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PRODUCT SUPPORTABILITY ISSUES IN THE EARLY DESIGN PHASES

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The goal of the Unified Life Cycle Engineering (ULCE) program is to develop enhanced design environments that will allow considerations of producibility and supportability of the product to be made early in the design process along with the usual factors of performance, cost, and schedule. This paper documents the issues involved with integrating consideration of product supportability in the early design phases. It contains a thorough description of the acquisition/design process for a selected hardware design problem, an airborne radar warning, and countermeasures equipment.

The major performance design goals and requirements typically considered in the design process for the selected equipment are given in detail; the measures for reliability, maintainability, and supportability (R,M&S) used at each level of the equipment breakdown are documented, and the shortfalls in the acquisition requirements documents that prevent the design process from ensuring a supportable product are identified. Specific recommendations are given for facilitating the consideration of supportability requirements. Appendices contain sample specification paragraphs for development specifications for use as a guide to specification preparation and sample paragraphs for use as a guide for Statement of Work preparation.

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INSTITUTE FOR DEFENSE ANALYSES

Contract MDA 903 89 C 0003
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PREFACE

This report is the result of work performed by the Institute for Defense Analyses (IDA) under contract number MDA 903 89 C 0003, task order T-D6-554, "Measurement Issues in Unified Life Cycle Engineering." This work was performed for the Air Force Human Resources Laboratory and the Under Secretary of Defense for Acquisition (USD(A)). The two general areas being investigated under the task are *supportability* and *producibility*. This report addresses the supportability issues in Unified Life Cycle Engineering.

This paper was reviewed by Dr. Jeffrey H. Grotte of IDA, Dr. Daniel P. Schrage of the Georgia Institute of Technology, and Mr. Frederick J. Michel, an IDA consultant.

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GLOSSARY

A	Percent maintenance actions requiring LRUs
A_i	Inherent availability
A_o	Operational availability
AFLC	Air Force Logistics Command
AGERD	Aerospace Ground Equipment Requirements Document
AN/ALQ-XXX	Hypothetical airborne radar warning and countermeasures equipment intended for use on a typical fighter/bomber aircraft
ARO	After Receipt of Order
ATE	Automatic Test Equipment
BIT	Built-In-Test
C	Percent LRUs allowed at organizational level
C_{CAE}	Computer-aided engineering parts requiring maintenance action
CALS	Computer-Aided Acquisition and Logistic Support
CLIN	Contract Line Item Number
CM	Countermeasures
D	Percent allowed parts satisfied from organizational stock
DFC	Diagnostic Flow Chart
DID	Data Item Description
DoD	Department of Defense
DoDD	Department of Defense Directive
dB	Decibel referenced to 1 milliwatt
DRFM	Digital Radio Frequency Memory
DSS	Decision Support System
E	Time required to obtain LRUs at the organizational level
EAROM	Electronically Alterable Read Only Memory
ECM	Electronic countermeasures
ECP	Engineering Change Proposal

EMI	Electro-Magnetic Interference
EMP	Electro-Magnetic Protection
F	Mean requisition time for depleted spares
FLU	First-Line Unit
FMEA	Failure Modes and Effects Analysis
FOM	Figure of Merit
FSN	Federal Stock Number
FY	Fiscal Year
GH_z	Gigahertz
GUIDEP	Government, University, and Industry Data Exchange Program
HVPS	High Voltage Power Supply
IDA	Institute for Defense Analyses
IF	Immediate frequency
ILS	Integrated Logistics Support
IRU	Intermediate Replaceable Unit
K	Usage Factor (available hours/year/operating hours/year)
LCC	Life Cycle Cost
LOR	Life Operations Research
LRU	Line-Replaceable Unit
LSA	Logistics Supportability Analysis
LSC	Logistics Support Cost
LSI	Large-Scale Integrated Circuit
LVA	Log Video Amplifier
M_{maxct}	Maximum time to repair
MDT_d	Mean downtime due to documentation
MDT_{oa}	Mean downtime due to outside assistance
MDT_{ops}	Mean downtime due to squadron operations
MDT_{or}	Mean downtime due to other reasons
MDT_s	Mean scheduled downtime
MDT_t	Mean downtime due to training
MENS	Mission Elements Need Statement
MHz	Megahertz

MIL-SPEC	Military Specification
MIL-STD	Military Standard
MOTBMA	Mean operating time between maintenance actions
MTBF	Mean time between failure
$MTBM_c$	Mean time between corrective maintenance
MTTR	Mean time to repair
MWR	Missile Warning Radar
OMB	Office of Management and Budget
PM&T	Personnel, Manpower, and Training
PRF	Pulse Repetition Frequency
QQPRL	Qualitative and Quantitative Personnel Requirements List
QRA	Quick Replaceable Assembly
R&M	Reliability and Maintainability
RAMCAD	Reliability and Maintainability Computer-Aided Design
RAW	Reliability Assessment Warranty
RF	Radio Frequency
RFI	Radio Frequency Interference
RFP	Request for Proposal
RGF	Range Gate Frequency
RIW	Reliability Improvement Warranty
R,M&S	Reliability, Maintainability and Supportability
RWR	Radar Warning Receiver
SE	Support Equipment
SOW	Statement of Work
SRU	Shop Replaceable Unit
TO	Transistor Outline
TWT	Traveling Wave Tube
UHF	Ultra High Frequency
USD(A)	Under Secretary of Defense for Acquisition
ULCE	Unified Life Cycle Engineering
UUT	Unit Under Test

VHF	Very High Frequency
VSWR	Voltage Standing Wave Ratio
WBS	Work Breakdown Structure

EXECUTIVE SUMMARY

The goal of the Unified Life Cycle Engineering (ULCE) program is to develop enhanced design environments that will allow considerations of product producibility and supportability to be made early in the design process, along with the usual factors of performance, cost, and schedule. Inherent in this objective is the need for design requirements and specifications in requests for proposals (RFPs) and statements of work (SOWs) to be formulated commensurate with this goal. This paper is the result of an investigation into the issues involved with the consideration of supportability in the early design and acquisition process.

A. BACKGROUND

In the spring of 1987, the Institute for Defense Analyses (IDA) held two workshops to investigate the decision support requirements in an ULCE design environment. Participants at these workshops were from industry, academia, and government and constituted the IDA ULCE Decision Support System (DSS) Working Group. The specific issue addressed by this group was as follows:

> What tools, techniques, and procedures are needed to allow considerations of producibility and supportability to be quantified and traded off with cost, performance, and schedule factors throughout the design process?

One research priority identified by the Working Group for ULCE DSS focus was "a search for methods to incorporate the qualitative factors of the design process into the formal and informal optimization procedures contemplated for ULCE." [Ref. 1] Since many components of the concepts of producibility and supportability are qualitative attributes, their potential for formal inclusion in an ULCE DSS depends on the ability to meaningfully trade them off with other design attributes to achieve a design balanced among performance, cost, schedule, producibility, and supportability.

Research into this priority item was funded by the Air Force Human Resources Laboratory, Logistics and Human Factors Division, as the FY 1988 IDA task,

"Measurement Issues in Unified Life Cycle Engineering." This paper is the result of an investigation under this task into techniques for evaluating designs with regard to their supportability characteristics.

B. OVERVIEW

For purposes of the discussion in this paper, the term supportability implies supportability design features that include the attributes for reliability, maintainability, testability, manpower, and skill considerations, since the issues presented apply equally to all. Specifically, this paper includes

- documentation of the major performance design goals and requirements that are typically considered in the design process for a selected hardware design problem,
- identification and documentation of the measures for supportability used at each level of the equipment breakdown for the selected hardware design problem, including information and computational requirements for such measures, and
- identification of the shortfalls in the acquisition requirements documents that prevent the design process from ensuring a supportable product.

A basic premise used as a guide in this study effort is that real-world design experience is crucial to understanding how supportability characteristics (or lack thereof) evolve in the design and development of equipment. As a result, the hardware selected for the design candidate was chosen from various equipment that two of the authors, Mr. David Owen and Mr. Siegfried Goldstein, had direct design involvement with. The specifications and requirements used in the study and cited in this report are actual, and the review and evaluation of the design process and the resultant design features represent what actually happened.

C. FINDINGS

1. Shortfalls in Acquisition Requirements Documents

Studies by industry associations (government-sponsored or voluntary) and attendant industry surveys have identified problems in the design process that hinder the delivery of supportable equipment at the lowest cost. The solution being sought is the integration of supportability and producibility considerations in the early design stages.

This solution is being worked in the ULCE, the Reliability and Maintainability Computer-Aided Design (RAMCAD), and the Computer-Aided Acquisition and Logistics Support (CALS) programs and similar initiatives, such as those on Concurrent Engineering. With few exceptions, designs are frozen during the proposal phase, where the design and cost commitments are binding. However, at this phase, design costs to the government are lowest. A case study illustrating the extent of the life cycle cost (LCC) leverage up front in the design process is provided in Appendix A, which contains viewgraphs presented by Mr. Goldstein at an ULCE technical interchange meeting.

As indicated in this study, competition forces the defense contractors to respond to the Request for Proposal (RFP) specifications, requirements, and evaluation criteria with designs that comply with the performance requirements and the quality assurance provisions. Other studies have concluded that if acquisition requirements were changed to include supportability requirements in the proper way, contractors would, by virtue of the fiercely competitive environment, do whatever was necessary to improve their design process to deliver more supportable products. The integration of supportability issues in an ULCE environment would be a necessary step in improving their design process. How the acquisition process could be changed to attain more supportable designs is not immediately clear, however, since a tightening of requirements does not necessarily force the integration of design disciplines. Some counter-productive acquisition practices are identified in the following sections.

a. The Master Specification Forces Segregation

MIL-STD-490, which governs specification preparation, dictates the separation of the performance requirements paragraphs from the supportability-related paragraphs in all attendant acquisition documents, RFPs, proposals, and proposal reviews. Such segregation provides for separate and orderly treatment of each type of requirement; however, the readers of one section of a document do not know the contents of the other sections unless they are forced to read them. It would be beneficial to the goal of ULCE if the performance requirements section, at least, alerted the reader to related supportability requirements. The integration of requirements is not forbidden, even if such integration results in repetition. In addition to the MIL-STD requirements, another reason why performance and supportability requirements are not effectively integrated is technical jargon. Some, if not most, of the supportability requirements are written in terms that do

not easily translate into design features, and they are relegated to the specialist for interpretation.

b. Supportability Requirements are not Need Oriented

The recommendation that supportability requirements be established by the systems engineer or user is contained in both the Office of Management and Budget (OMB) Circular A-109 and Department of Defense (DoD) Directive 5000.1, *Major System Acquisitions*, although expressed differently in each. These documents state, in no uncertain terms, that the acquisition documents should assert only what is wanted and needed--not how to achieve it. Contemporary acquisition documents, however, attempt to provide a solution without ever posing a problem; this is especially true in the supportability area. This shortfall can be rationalized a number of ways:

- The systems engineer is concerned with performance and has no time to translate performance functions into supportability requirements.
- The systems engineer is concerned only with an operational system and cannot visualize or address failures.
- The supportability engineer has no idea which performance parameters are more essential than others.
- The supportability engineer has no notion of how much a performance requirement can be degraded before a part or all of the mission is compromised.

c. Supportability Metrics are not Universally Understood

Supportability metrics are considered to be adequate for support planning and support resource acquisition purposes. An exception is the manner with which fault isolation ambiguities are usually specified. Ambiguities should not be allowed, at least at the Shop-Replaceable Unit (SRU) and sub-SRU levels, since they force the procurement of extra, unnecessary spares. (The problem has been recognized and is being addressed by OSD's Integrated Diagnostics initiative.)

The application of some of the supportability metrics for design guidance and trade-off purposes engenders a number of problems. Trade-offs among supportability issues involves the many metrics with which they are measured (see Section III.D). These metrics are diverse, ranging from time-related events (mean time between failures (MTBF) and mean time to repair (MTTR)) and cost-related events (such as fault isolation ambiguity

groups, repair level, repair turnaround times, and support equipment loading), to manpower events (task requirements and skill requirements). If automated trade-offs are to be performed among these metrics, they must all be translatable to the same metric. The trade-off problem is further complicated when the supportability attributes must be balanced with the attributes of performance, cost, and schedule.

Most supportability-related metrics are based on the probability that a maintenance action is required. This concept in turn is based on reliability metrics that employ the probability of failure. Maintenance-action metrics are based on common time and motion studies that result in a measure of how long it takes a person with a certain skill to perform a given action. These measures are also converted to statistics to assess the mean time of such actions.

A design engineer, unless trained in the Reliability, Maintainability, and Supportability (R,M&S) discipline, has difficulty relating to the maintenance statistics, except for parts selection. Even some reliability engineers are hard pressed to answer the commonly posed question: "Does MTBF apply to one item (one part number with one serial number) over its total life or to the sum of all like items over their total lives?" Regardless of how this question is answered, it is difficult to determine how well an item will perform in a given situation. Statistics such as MTBF only serve to determine spares buys, stockpiling, and manpower requirements and support resource loading.

Equally confusing are the statistically based requirements for built-in-test (BIT) false alarm rates. Expressed as percentile, these requirements are open to many interpretations. For example, the BIT requirement is usually specified as a capability of detecting 98 percent of all possible faults, with an attendant table of allowable fault isolation ambiguities and, say, a 0.5 percent false alarm rate. The worst (but perfectly legitimate) interpretation of this requirement is that the 0.5 percent applies to the number of tests performed--that 99.5 percent of the BIT test routines provide the proper answer. Thus, if a thousand tests were conducted per second, a three-hour mission could be plagued by 540,000 false alarms and still meet the requirement.

In meeting the same BIT requirement, a design whose simple but high-failure-rate power supply accounts for 90 percent of the system's failure rate could be tested with one or two simple test points. The 8 percent of the failure rate accounted for by the remainder of the system could then be tested by some more complex means. It is not unusual to find that the heart of a system--a digital processor or special purpose computer that accounts for

less than 2 percent of the failure rate--can remain untested and still meet the statistically-based requirements.

D. RECOMMENDATIONS

Based on the preceding discussion, the following general recommendations are made:

- Supportability requirements must be written in terms that easily translate into design features to facilitate integration of supportability and performance requirements.
- Supportability requirements must be established by the systems engineer or user to be need oriented instead of solution oriented.
- Supportability specifications must be appropriately written into the Statement of Work (SOW) and the quality assurance provisions of a development specification.

These recommendations demand that more effort be expended in specifying performance requirements. Acceptable performance tolerances must be clearly stated, along with what the system must do when those tolerances are exceeded. The requirements must specify what excursions are tolerable upon mission start-up and throughout the mission, including action and reaction statements. For example, in a tail warning radar, the identification of a threat and the potential warning of a kill is life essential. If the detection range were specified as 200 miles for a particular missile and reaction to the threat required the equivalent time (in terms of closing speed) of 3 decibel (dB) of radar range, the specification should state that a 3 dB degradation of radar range, transmitted power, or degraded sensitivity must alert the pilot to take specified evasive maneuvers.

To ensure that systems meet such essential requirements, preparation of requirements documentation requires a great deal of effort from the systems engineer, but enhanced design environments are being developed that will aid such efforts. By specifying needs in this way, the supportability requirements, formerly understood only by specialists, will be easily translated into intrinsic design features that solve the stated problems.

To ensure design engineering and management recognition and support of ULCE principles requires appropriate statements in the SOW and in some portions of the quality assurance provisions of a development specification. Appendix B contains sample

specification paragraphs for development specifications which can be used as a guide to specification preparation. The guide emphasizes quality assurance provisions and ranking of requirements by mission criticality. Appendix C contains sample paragraphs to be used in preparing SOWs.

I. INTRODUCTION

The goal of the Unified Life Cycle Engineering (ULCE) program is to develop enhanced design environments that will allow considerations of product producibility and supportability to be made early in the design process, along with the usual factors of performance, cost, and schedule. Inherent in this objective is the need for design formulating requirements and specifications for requests for proposals (RFPs) and statements of work (SOWs) that are commensurate with this goal. This paper is the result of an investigation into the issues involved with the consideration of supportability in the early design.

A. BACKGROUND

In the spring of 1987, the Institute for Defense Analyses (IDA) held two workshops to investigate the decision support requirements in an ULCE design environment. Participants at these workshops were from industry, academia, and government and constituted the IDA ULCE Decision Support System (DSS) Working Group. The specific issue addressed by this group was as follows:

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Research into this priority item was funded by the Air Force Human Resources Laboratory, Logistics and Human Factors Division, as the FY 1988 IDA task,

"Measurement Issues in Unified Life Cycle Engineering." This paper is the result of an investigation under this task into techniques for evaluating designs with regard to their supportability characteristics.

B. TASK OBJECTIVE AND APPROACH

The task objective addressed in this report is the investigation of techniques for evaluating designs with regard to their supportability characteristics. Specifically, the objectives were to

- document the major performance design goals and requirements that are typically considered in the design process for a selected hardware design problem,
- identify and document the measures for reliability, maintainability, and supportability (R,M&S) used at each level of the equipment breakdown for the selected hardware design problem, including information and computational requirements for such measures, and
- identify the shortfalls in the acquisition requirements documents that prevent the design process from ensuring a supportable product.

A basic premise used as a guide in this study effort is that real-world design experience is crucial to understanding how supportability characteristics (or lack thereof) evolve in the design and development of equipment. As a result, the hardware selected for the design candidate was chosen from various equipment that two of the authors of this report, Mr. David Owen and Mr. Siegfried Goldstein, had direct design involvement with. The specifications and requirements used in the study and cited in this report are actual, and the review and evaluation of the design process and the resultant design features represent what actually happened on similar equipment.

C. REPORT ORGANIZATION

This report is organized along the lines followed in the study, and the major sections are directly related to the three areas of investigation identified in the preceding paragraph.

Chapter II, *Hardware Design Candidate*, describes the selection process used for the case study and contains the top-level equipment requirements and a description of the

selected system. It also includes a discussion of hardware design features that are directly related to supportability.

Chapter III, *Reliability, Maintainability, and Supportability Metrics*, addresses the design process in relation to the proposal/acquisition cycle and the current state of R,M&S requirements. It identifies a number of trade studies that are typically conducted in a design of this type and their effect on equipment design.

Chapter IV, *Acquisition Requirements Documents--Findings and Recommendations*, discusses a number of specific problem areas in the specification of supportability requirements and includes recommendations designed to influence the consideration of supportability in the early design phases.

Appendices D and E contain sample paragraphs for improved R,M&S specifications and Statements of Work (SOWs) for hardware development.

II. HARDWARE DESIGN CANDIDATE

A. EQUIPMENT SELECTION

To realistically represent some of the difficulties and shortcomings of the current design process, using real-world equipment as an example is desirable. However, the difficulties associated with that approach, such as security issues and proprietary data, would seriously hamper the effort. To avoid these limitations, it was decided to combine selected technical features and requirements from a number of real systems in a composite hypothetical system. The result is the AN/ALQ-XXX, an airborne radar warning and countermeasures equipment intended for use on a typical fighter/bomber aircraft.

The systems used as models and from which requirements and design features were drawn were all developed in the late 1970s and early 1980s and provide a good cross section of airborne equipments being deployed today.

1. Composite System

In developing a composite candidate system to be used in the study, it was important that supportability issues truly interacted with other requirements in the design of the equipment--that the candidate system posed real design trade-offs and decisions among supportability, performance, cost, and schedule requirements. In addition, the support-related requirements had to come from actual specifications and designs in order to develop a realistic representation.

The system comparison in Table II-1 contains the major characteristics of four existing airborne systems and the selected characteristics of the composite system, the AN/ALQ-XXX. The selections were made to yield a system that would reasonably meet a current requirement, be moderately complex, and represent equivalent equipment or systems in design and development today.

Table II-1. System Comparison

FEATURES	SYSTEMS				
	AN/ALQ-ZZZ (COUNTERMEASURES)	AN/ALQ-XYZ (COUNTERMEASURES)	AN/ALQ-XYY (TAIL WARNING RADAR)	AN/ALQ-YYY ESM/ECM	AN/ALQ-XXX CANDIDATE
ANTENNAS	Not included–uses RWR system antennas forward and aft	Multiple frequency 360° coverage	Single frequency Aft coverage (4 antennas)	Full spectrum Multiple polarization 360° coverage and scanning antennas	Multiple frequency 360° coverage
RECEIVERS	Broadband superheterodyne and digital RF memory	Multiple bandwidth • Compressive • Narrowband superheterodyne • Scanning superheterodyne	Single frequency/range gate frequency (RGF) (Doppler) superheterodyne	Multiple very broadband • Channelized superhet • Crystal video	Crystal video and compressive superhet
TRANSMITTER	Wideband multiple modulations	Wideband Travel Wave Tubes Multiple modulation (separate transmit (TX) antenna)	Single frequency High pulse rate frequency (PRF) - pulse TWT	Multiple TWTs Very wideband Multiple techniques Power managed	Wideband TWT Multiple techniques Single threat
SIGNAL PROCESSOR	RF processing	Preprocessor and data encoders	Doppler processing Detect and track	RF processing and preprocessors	RF and preprocessor
DATA PROCESSOR	Distributed micro- and macro-processors	AN/AYK-14s	None	Distributed micro- and macro-processor	Distributed micro- and macro-processor
DATA DISTRIBUTION	Special data bus	1553 data bus	Hard wired	Hard-wired and data bus technique	Unique data bus
INTERFACE	Functional at high and low level	System status and control to other aircraft systems	Standalone	System status to other aircraft systems	System status to other aircraft systems on 1553 data bus
NO. OF LRUs	4	12	5	120	10-12
SYSTEM FUNCTION	Radar jammer	Communications jammer	Tail warning radar	Radar warning/ECM and radar jammer	Radar warning, limited jamming, and integrated tail warning

Although the functional and performance requirements included for the AN/ALQ-XXX are, in large measure, hypothetical, the supportability requirements, specifications, and design features are not. They are actual, extracted and assembled from documentation on the four systems that compose the AN/ALQ-XXX.

2. System Description

The system requirements for the AN/ALQ-XXX Airborne Countermeasures Set can be categorized into two areas: functional and operational. The two are interrelated and, to a great degree, interdependent with respect to the equipment design.

a. Functional

The AN/ALQ-XXX is intended for use on a fighter/bomber aircraft in tactical close support and strategic low-level attack missions. Its role is self protection only; it is not intended for use as a stand-off jammer. The following four subfunctions are incorporated in the equipment.

Radar Warning Receiver (RWR). The system will provide a warning of aircraft illumination by ground or airborne radars, either surveillance or fire control types. It will also detect, identify, and display warnings of ground-to-air and air-to-air missile radars. Display information will consist of threat type and direction of arrival. The radar warning function also supplies threat data for use in assigning, controlling, and optimizing the radiated electronic countermeasure signals.

Electronic Countermeasures (ECM). The active countermeasures portion of the system will provide jamming signals against missile and airborne fire control radars in the X-band and K-band frequency range. It is capable of power management and a wide range of jamming techniques to counter multiple simultaneous threats. The functional design incorporates an agile tracker and a digital radio frequency memory (DRFM).

Communications Jammer. The communications jamming function of the AN/ALQ-XXX is designed to counter the ground-controlled intercept threat and will operate against both voice and data links of either ground-to-air or air-to-ground communications in the very high frequency (VHF) and ultra high frequency (UHF) range.

Missile Warning Radar. The missile warning radar provides an active means of detecting ground-to-air or air-to-air missiles launched against the host platform. It provides

target detection, threat evaluation, and countermeasures activation signals for chaff, flares, or ECM. It operates in both forward and aft sectors.

b. Operational

The AN/ALQ-XXX will be used primarily in tactical support missions on fighter/bomber aircraft. Although the aircraft will be capable of in-flight refueling, most missions will be operated from forward area airfields, requiring rapid turnaround and sustained high sortie rates. A typical mission profile is

Ground operation	30 minutes
In-flight	2 hours
Turnaround (ground)	1 hour
BIT/performance monitor	Pre-flight and in-flight at operator discretion. Ground operation is limited to non-radiate mode
System maintenance time	Considered part of the turnaround time between sorties
Organizational mean time to repair (MTTR)	30 minutes for 95 percent of failures; 60 minutes maximum, exclusive of aircraft access.

A portion of the AN/ALQ-XXX equipment may be pod mounted. When the aircraft is configured without a pod, the radar warning function of the system will remain operational, and no change will be required to the onboard equipment or software.

B. EQUIPMENT DESCRIPTION

A simplified block diagram of the AN/ALQ-XXX is shown in Figure II-1. Central control of all major system functions resides in a dedicated AN/AYK-14 computer, along with the threat library data.

1. Radar Warning Subsystems

The principal elements of the radar warning subsystems are contained in the antenna/radio frequency (RF) amplifier and the pulse encoder line replaceable units (LRUs). Four of each unit provides quadrant coverage around the aircraft. Each antenna/RF amplifier unit contains three broadband antennas and three RF amplifiers. The amplified RF is sent to the pulse encoder unit, where it is detected in a log video amplifier

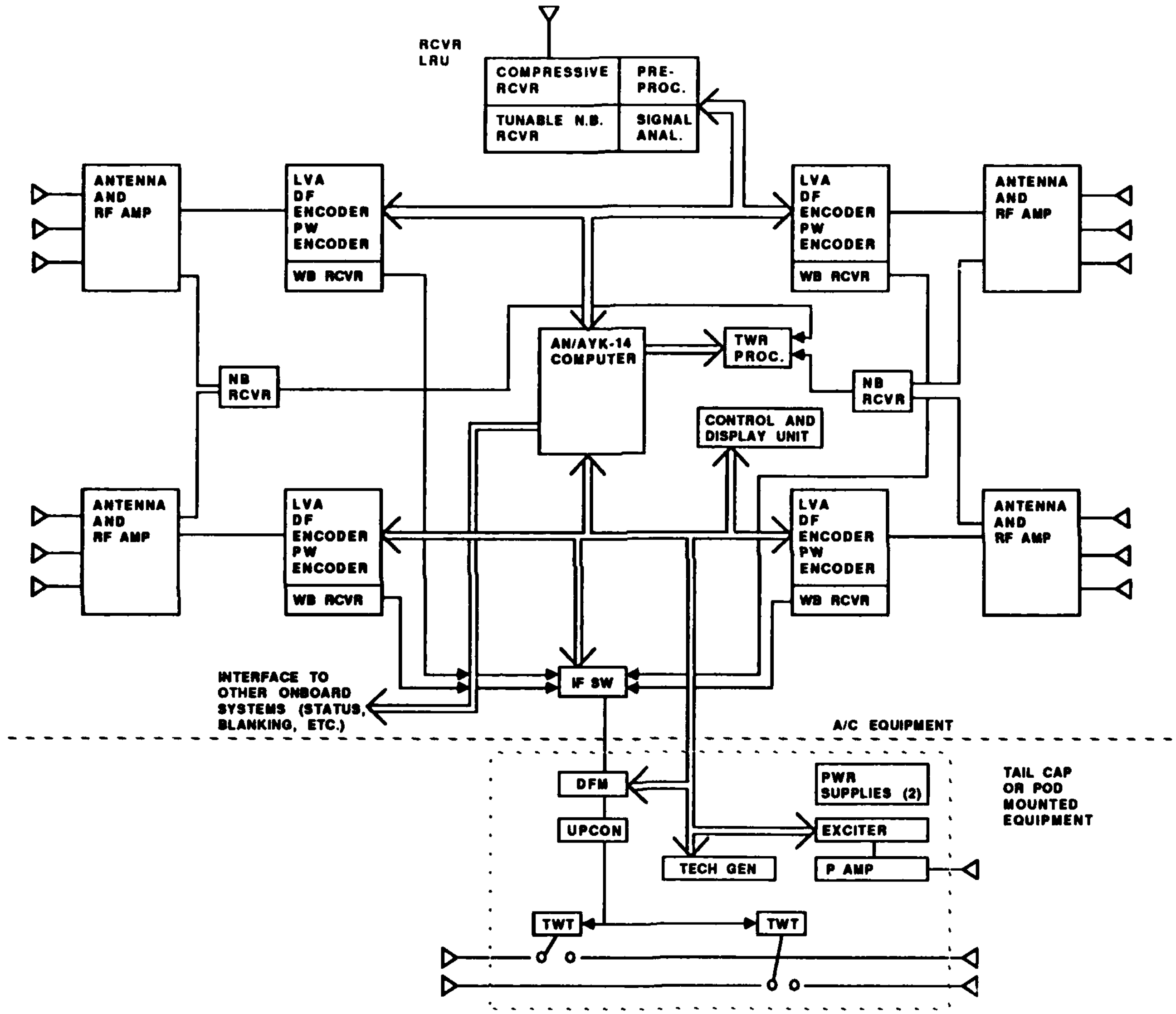

Figure II-1. AN/ALQ-XXX Airborne Countermeasures Set

(LVA) and digitally encoded in a pulse descriptor word. The pulse descriptor contains pulse amplitude, pulse width, and time of arrival information. The pulse descriptor is then sent to the AN/AYK-14 on the digital data bus. The encoder LRU also contains a multistage wideband receiver covering the operating range of the ECM subsystem.

2. Electronic Countermeasures Subsystem

The active countermeasure subsystem uses the radar warning data to identify and assign threats for jamming. Threat assignment information is sent to the wideband receiver in the encoder to select the threat received signal and gate it to the DRFM. Threat data are also sent to the DRFM and the technique generator to generate the proper response to the threat.

Two traveling wave tubes (TWTs) and two sets of transmitting antennas cover the ECM operating frequency range. (The frequency range of the ECM subsystem is less than that of the radar warning subsystem.)

The ECM transmitting antennas are located in the aircraft tail cap or in an external pod, to provide maximum separation between the radar warning receive antennas and the active ECM antennas.

3. Communications Jammer

The receiving portion of the communication jammer equipment is contained in a single LRU. It consists of a compressive receiver for rapid signal intercept and an associated acquisition preprocessor. The preprocessor digitizes the signal intercepts and sends them, via the digital data bus, to the AN/AYK-14. Based on the evaluation of intercepted signals, the narrowband receiver is tuned to signals of interest for detailed analysis in the signal analyzer, also located in the receiver LRU. The results of the signal analysis are sent to the AN/AYK-14 for further evaluation and jamming assignment. Jamming decisions are sent via the data bus to the jamming pod (or tail cap). The jamming data word commands the exciter to create a suitable jamming signal from its repertoire, and the resulting jamming signal is amplified in the power amplifier and transmitted via the omnidirectional jamming antenna.

For a pod-mounted installation, the receiving antenna is mounted on the top centerline of the aircraft and the transmitting antenna on the bottom of the pod. For a tail cap installation, the receiving antenna is located on the bottom centerline of the aircraft.

4. Missile Warning Radar

The missile warning radar (MWR) subsystem is integrated into the radar warning and ECM functions in the AN/ALQ-XXX, and they share a number of equipments.

The radar-transmitted signal is a pulsed signal generated in the ECM transmitter chain. Timing of the radar transmissions is controlled by the AN/AYK-14. The transmitter is alternately switched to forward and aft antennas. The radar return from a target is received by the in-band antenna of the antenna/RF amplifier LRU and coupled to a narrowband receiver, converted to intermediate frequency (IF), and sent to the MWR processor. The processor detects, identifies, and classifies the target type and sends the data to the AN/AYK-14. Target information is sent to the operator's control and display unit. The AN/AYK-14 also evaluates target data for control of expendable countermeasures, such as chaff and flares.

Aircraft installation requirements of the missile warning radar include that the pod interface be in accordance with MIL-STD-1760A and that the onboard aircraft systems interface be in accordance with MIL-STD-1553.

C. SYSTEM REQUIREMENTS

The requirements that govern the design of any system or equipment are usually found in the equipment specifications. In the case of the AN/ALQ-XXX, they were contained in the Prime Item Development Specification prepared by the government and provided as part of the RFPs for the various systems that AN/ALQ-XXX is based on.

The format and content of any specification prepared by the government are well defined and dictated by MIL-STD-490, *Specification Practices*. Typical specifications prepared in accordance with MIL-STD-490 contain the following six sections:

- Scope
- Applicable Documents
- Requirements
- Quality Assurance Provisions
- Preparation for Delivery
- Notes.

Of these six sections, three have a major influence on the design of the prime equipment. These sections, in the order of their effect, are Requirements, Applicable Documents, and Quality Assurance Provisions.

The effect of the Requirements section is obvious in that it specifies, usually in great detail, the functional and performance requirements of the equipment.

The Applicable Documents section imposes the requirements of a myriad of MIL-STDs and Military Specifications (MIL-SPECs), many of these also containing numerous levels of detail. During the design of an equipment, finding conflicts between the requirements section and requirements buried in the details of a referenced MIL-STD or MIL-SPEC is not unusual. The possibility of conflicts is usually (but not always) addressed by a caveat included in the prime equipment specification, which gives the order of precedence of different requirements.

The Quality Assurance Provisions section of a specification has a major effect on the design of equipment. This is particularly true for the area of supportability, because the Quality Assurance section defines the acceptance test requirements, quite often in far more detail than the Requirements section of the specification.

1. AN/ALQ-XXX Performance Requirements

The system performance requirements for the AN/ALQ-XXX Airborne Countermeasures Set were addressed at various indenture levels in the equipment specification. An example of the breakdown of different parameters is as follows:

- System Level
  - Size
  - Weight
  - Environment
  - Mission requirements
- Subsystem Level
  - Radar Warning
    - Frequency range
    - Coverage
    - Threat resolution

- Equipment Level
    - Antenna
        - -- Gain
        - -- Sidelobes
        - -- Beamwidth
    - Receiver
        - -- Noise figure
        - -- Bandwidth

A sample of some of the detailed performance specifications for the AN/ALQ-XXX at the subsystem and equipment level follows.

Radar Warning Receiver

Frequency Coverage	0.9 GHz to 18 GHz
Sensitivity	-60 dBm or better -50 dBm worst case
Receiver Bandwidth	10 MHz
Radar Identification	1. Lethal available countermeasures (CM) identified 2. Guidance 3. Passive
Radar Coverage (Threat Resolution)	16 threats per receiver antenna, prioritized
Doppler Blanking	2 threats per receiver antenna
Threat File	80 threats minimum 20 unknowns (spares)
False Alarm (Detection) Rate	1 in 106 pulses
Spatial Coverage	360° azimuth L-Band through S-Band: + 10°, -55° elevation X-Band through K-Band: +3°, -30° elevation
Direction of Arrival Accuracy	L-Band through S-Band: quadrant (+/-10°) X-Band through K-Band: +/-10° average
Antenna Polarization	Right-hand circular

Antenna Gain	L-Band through S-Band	6 dB
	Low X-Band	10 dB
	Low K-Band	15 dB
Voltage Standing Wave Radio (VSWR)	2.5:1 at any frequency	
Sidelobes	-20 dB maximum	
Backlobes	-50 dB maximum	

Although the complete performance specification was much more extensive, the sample provided indicates the principal areas of interaction between design for performance and design for supportability. In the case of the AN/ALQ-XXX, the two most significant areas of interaction were the design of the built-in-test (BIT) and the physical location and mechanical design of the equipment necessary to meet the functional requirements and the associated effect on maintainability.

2. AN/ALQ-XXX Supportability Requirements

The following are the primary supportability requirements for the AN/ALQ-XXX, obtained from the specifications of the systems that its design was based on.

a. Reliability

The design-to reliability of the AN/ALQ-XXX Countermeasures Set shall be 450 hours mean time between failure (MTBF) when tested in accordance with the quality assurance provisions herein. The mean operating time between maintenance actions (MOTBMA) shall be a minimum of 150 hours as experienced on mature systems in actual operation.

b. Useful Life

The AN/ALQ-XXX shall be designed for an operating life of at least 15 years and a storage life of 2 years.

c. Reliability Design Criteria

The AN/ALQ-XXX shall be designed to meet all specified reliability requirements. To the extent possible, the design shall preclude failure of one component causing failures of other components. The following requirements apply:

- Peak junction temperatures of semiconductors shall not exceed the following:
  - Power devices - 135° C (275° F)
  - Small signal devices - 125° C (257° F).
- Maximum junction temperature of integrated circuits and small signal transistors and diodes shall not exceed 125° C (257° F) under any conditions.

d. Maintainability

The AN/ALQ-XXX shall be maintained using the principle of three-level maintenance.

e. Organizational Level Maintenance

The maximum time to repair (M_{maxct}), which 95 percent of all organizational corrective maintenance will be completed within, shall not exceed 30 minutes. M_{maxct} time to repair includes all tasks (fault verification, isolation, remove, replace, repair, and checkout, as defined in MIL-STD-471). All fault detection and isolation shall be performed with the BIT. Simple, standard auxiliary test equipment is permitted to isolate to the correct LRU within the allowable ambiguity ratio.

f. Built-in-Test

BIT shall be self contained and consist of continuous BIT to check items contributing to more than 60 percent of the system failure rate. Other BIT checks shall be under the control of the operator and shall report status to the cockpit control panel. The onboard AN/AYK-14 computer will time share the navigation memory for BIT routine execution, as defined in the operations schema. The BIT circuits shall fail in such a manner that the computer memory is released for other functions, and a BIT failure is declared to the operator.

BIT shall detect 92 percent of all possible faults when operating within its full repertoire; 98 percent of the detected faults shall be isolated to the faulty LRU without ambiguity. BIT false alarm rate shall be no greater than 1 percent per mission. Failure information shall be permanently stored and survive power shut-down.

Pre-flight and in-flight tests during periods of radio silence shall not cause signal radiation exceeding 10 milliwatt.

g. Maintenance Actions

LRU removal from the aircraft shall require only one man and shall be accomplished within 15 minutes. The ratio of LRUs that weigh less than 40 pounds and can be removed by one man to those that cannot must be greater than 0.90.

There shall be no scheduled maintenance actions.

h. Intermediate-Level Maintenance

Intermediate-level maintenance shall be limited to the repair of LRUs by removal and replacement of shop-replaceable units (SRUs) and chassis-mounted components. The LRUs must be compatible with the approved automatic test equipment (ATE). The MTTR for an LRU with ATE is 45 minutes.

- All inputs and outputs, including test points, must be compatible with the capabilities of ATE. Neither ATE nor the unit under test (UUT) shall be able to be damaged during test.
- No signal conditioning devices shall be required to be employed between the UUT and ATE.
- No additional test equipment shall be required.
- Other than observing the console controls, no operator intervention shall be required in the use of ATE (hands-off maintenance).
- A fault within an LRU shall be isolated to the malfunctioning SRU non-ambiguously as follows:
    - To a single SRU for 90 percent of the MTBF of the LRU.
    - To an ambiguity of two SRUs for 95 percent of the MTBF of the LRU.
    - To a maximum ambiguity of three SRUs.
- Test points for isolating to SRUs must be contained on the next higher level assembly.
- Test points must terminate at connectors.
- Test points must not affect performance of the circuit being monitored.
- Test points must meet the safety requirements of MIL-STD-454.

i. Depot-Level Maintenance

Depot-level maintenance shall be limited to the repair of SRUs by removal and replacement of SRUs and chassis-mounted components. The SRUs must be compatible with the available ATE as defined in the Integrated Logistics Support (ILS) Specification. The MTTR for an SRU with ATE is 60 minutes, including repair of conformal coatings, if any.

- All inputs and outputs including test points must be compatible with the capabilities of ATE. Neither ATE nor the UUT shall be able to be damaged during test.
- No signal conditioning devices shall be required to be employed between the UUT and ATE.
- No additional test equipment shall be required.
- Other than observing the console controls, no operator intervention shall be required in the use of ATE (hands-off maintenance).
- A fault shall be isolated within a reparable SRU to its components af follows:
    - For SRUs containing 10 or less components, isolation to 2 or less components for 50 percent of the MTBF of the SRU. A maximum ambiguity of 4 components is permitted.
    - For SRUs containing more than 10 components, isolation to 4 or less for 80 percent of the SRU's MTBF, 8 or less for 95 percent of the MTBF, and a maximum ambiguity of 10 components.
- Test points must terminate at connectors.
- Test points must not affect performance of the circuit being monitored.
- Test points must meet the safety requirements of MIL-STD-454.

j. Non-Repairable Items

Items costing less than $100 and exhibiting an MTBF greater than 1,000 hours shall be deemed non-repairable and discarded upon failure at the intermediate level of maintenance.

k. Environmental Conditions

The AN/ALQ-XXX shall be designed and constructed to meet any individual or probable combination of service conditions specified herein without mechanical or electrical damage or performance degradation.

(1) Temperature

When exposed to these low and high temperatures extremes:

- Non-operating, transit, storage: -57° C (-70° F) to +68° C (+155° F)
- Operating: -51° C (-60° F) to +68° C (+155° F).

(2) Solar Radiation

Operating and non-operating modes when exposed to solar radiation of 104 watts per square foot (1,119 watts per square meter) and an ambient temperature of +49° C (+120° F) plus solar.

(3) Pressure

When exposed to atmospheric pressure of 800 mm (31.4 inches) to 140.7 mm (5.54 inches) of mercury in transit, storage, or non-operational mode and of 800 mm (31.4 inches) to 428.9 mm (16.9 inches) of mercury in operating mode.

l. Design and Construction

(1) Materials, Parts, and Processes

Parts, materials, and processes shall conform with the requirements in paragraphs 3.3, 3.4, and 3.5 of MIL-E-4158, except for specific requirements stated herein in conflict with MIL-E-4158.

(2) Standard and Commercial Parts

All parts employed in the manufacture of the equipment shall be selected in accordance with MIL-D-4158 and MIL-STD-965. Approval from the procuring activity for the use of all parts is required in accordance with MIL-STD-965. The following additional requirements apply:

(a) All semiconductors shall be selected in accordance with requirement 30 of MIL-STD-154 and the following:

- Only solid glass metallurgically bonded axial lead diodes and rectifiers shall be used.
- When transistor outline (TO) 5 and TO-18 packages are required, they shall be limited to the solid metal header type.
- All semiconductor device functions must be protected, and no plastic (polymeric or organic) or desiccant materials shall be included in the package.
- Thermo-compression wedge bonding shall not be used with aluminum wire.
- Aluminum TO-3 package shall not be used.
- No germanium devices shall be used without specific approval of the procuring activity.

(b) All microelectronic devices shall be selected in accordance with requirement 64 of MIL-STD-454 and the following:

- Custom-designed integrated and hybrid circuits shall be avoided unless no reasonable alternative exists. Hybrid and complex monolithic microcircuits are considered critical items and shall be treated in accordance with MIL-STD-785, task 208.

(3) Wiring

All wiring used in AN/ALQ-XXX components shall be in accordance with MIL-W-16878.

(4) Printed Wiring

Printed wiring, including multilayer printed wiring, shall conform to the design requirements of MIL-P-55110, except for non-repairable modules. When printed wiring boards are conformal coated, buffering (sleeving) of glass and ceramic components shall not be required.

(5) Hardware

All subassemblies of AN/ALQ-XXX components that are required to be assembled or disassembled shall be secured with captive hardware. All hardware necessary for installation or operation shall be provided as part of the component. All screws, handles,

hinges, and other related devices shall be in accordance with MIL-STD-454, requirement 12.

(6) Electronics Construction

The AN/ALQ-XXX shall be designed for maximum simplicity and speed of maintenance, consistent with minimum cost, weight, and volume of replacement spares. The design shall facilitate disposal rather than repair of failed subassemblies, where justified by the repair level analysis. Subassemblies shall be designed and located for maximum interchangeability and test accessibility. Relays and other electromechanical switching devices shall be kept to a minimum. Relays shall be hermetically sealed. Other electromechanical devices shall be either hermetically sealed or enclosed in dust covers. Circuit design shall be based upon "worst-case" design, which is consistent with minimum-maximum semiconductor rating and power supply operating voltage tolerance. Subassemblies shall be securely fastened in the installed position. Subassemblies shall be provided with test points and shall require no unsoldering or removal of wires for replacement.

(7) Keying

All plug-in subassemblies and cables shall be mechanically keyed and color coded to prevent error in replacement.

(8) Solid-State Microelectronic Design

The AN/ALQ-XXX shall be of solid-state design emphasizing maximum reliability, maintainability, and operational efficiency. Microelectronic device terms and definitions shall be in accordance with MIL-M-38510. Discrete semiconductor devices shall be Type TX only and shall be selected in accordance with MIL-STD-701. Selection and use of microcircuits shall require the specific written approval of the procuring activity. All solid-state devices and all microcircuits employed shall be in hermetically sealed packages.

D. DESIGN FEATURES

The following design features were developed during the proposal phase of several electronic countermeasures systems. These features, combined into the hypothetical AN/ALQ-XXX, deal primarily with supportability requirements and are described in terms

that the supportability reviewers are familiar with. The descriptions address the specified reliability and maintainability requirements, as well as maintenance restrictions.

References are made to the technical volume of the hypothetical proposal for the AN/ALQ-XXX, which would contain sketches and detailed descriptions of the items and/or design features. This cross referencing was done to substantiate the claims of the supportability portion of the proposal, since the technical volume contains the actual design features. The design features described also address the evaluation criteria of high operational availability at low life cycle cost for which more detail is found in Section III.F. The R,M&S design features can be summarized as follows:

- Multiple BIT routines tailored to the performance function under test.
- Automatic and manual BIT routines can
  - Eliminate false alarms.
  - Reduce operator error.
- Failure information capture and storage.
- LRU BIT flags remain set with power removed.
- Unambiguous fault isolation to LRUs.
- LRUs individually removable from aircraft.
- LRUs require no adjustment upon installation.
- LRUs have screw-type hold-downs.
- LRUs fit into existing mounting provisions.
- LRU connectors can be quickly disconnected and are scoop proof.
- LRUs are less than 40 lbs. in fuselage.
- LRUs are less than 10 lbs. in vertical stabilizer.
- LRUs are testable by BIT or ATE when out of aircraft.
- LRUs are repairable at intermediate or depot level.
- LRUs are subdivided into functionally packaged SRUs.
- Fault isolation to SRUs is unambiguous.
- SRUs and sub-SRUs are partitioned at circuit nodes.
- Foolproof mounting and connecting features are included.
- Digital SRUs are plug-in type.

- Components are removable from one side of the circuit board.
- IRU internal cabling does not hamper SRU removal.
- SRUs are repairable at intermediate or depot level.

1. Organizational Level

a. Choices of Optimum Maintenance Procedures

The following areas for optimization of equipment design and support resource design were identified during the proposal phase in accordance with the design freedom permitted by the Air Force:

- BIT features
- LRU construction and mounting features
- All solid-state design except for the TWT and high voltage power supply (HVPS)
- High degree of commonality
- Liquid pod cooling using identical Coolanol as used in the other pods
- Fundamental packaging/mounting concept of SRUs.

b. Built-In-Test Rationale

The LSA process considers the elements of the system design relating to mission success and equipment operational availability (discussed in Section III.F). The AN/ALQ-XXX uses three BIT routines (continuous background, continuous monitoring, and manually initiated) to provide a complete check of the performance functions. The design of the routines was based on the elements that are performance-critical for the circuit being checked, so that a degradation or failure is immediately recognized. The process includes the following:

- Frequency sensitive circuits are checked at several frequencies.
- Low-level signals are used for amplitude-sensitive circuits to check sensitivity and gain.
- Circuits in which linearity is essential are tested with an amplified BIT signal.
- Transmitting antennas are checked by VSWR measurement.
- Digital circuits are checked with checkerboard patterns and continuous parity checks.

- Memories are checked with checkerboard loading, check sums, and instruction sets stacked through the registers.
- Transmitters are checked with one or two low-level pulses looped back through the receivers.
- Circuits that generate critical outputs are monitored continuously, and their status is reported to the computer (for example, power supplies, clock, synthesizer phase lock loop, critical temperature sensors, and transmitter power output).
- Continuous background routines are controlled by the AN/AYK-14 computer to automatically check performance functions individually, as well as in combination with end-to-end tests. BIT signals are also switched between input to the antennas (via probes) and the inputs of the receivers, to provide unambiguous fault isolation to the LRUs and, at the same time, provide checkout and isolation of antennas and transmission lines. Ambiguities between LRUs are broken by LRU self checks with LRU self-contained BIT.
- The ability to switch BIT signal paths enables the same BIT routines to be used for manually initiated routines and fault isolation, thereby simplifying software and the amount of dedicated BIT circuitry. BIT routines check virtually all of the components automatically in 14 cycles of varying BIT signal parameters and processing routines. The first cycle detects 87 percent of the failure rate and more than 97 percent is attained by the 14th cycle--still without manual intervention.

Manually initiated BIT adds to the continuous BIT by loading a full test instruction set through the memory and using extended checkerboard testing processing, which is much more comprehensive than the background check. It checks the ability to run the mission program, but limited computer memory allocation to the AN/ALQ-XXX requires that the mission program be reloaded, as is routinely done prior to a mission. Manual BIT also checks all the switching paths, attenuator settings, bandwidths, and operator display indicators. This provides a check on an additional 1.5 percent of failure rate.

c. False Alarm Elimination

False alarms, which are normally experienced in such a comprehensive BIT, are eliminated by automatic retest in pre-determined cycles for fault confirmation, resulting in 0.3 false alarms per mission without operator intervention. Manual retest for confirmation can reduce false alarms to zero. In addition, false alarms are held to a minimum by

avoiding hair trigger circuits that latch up to indicate a fault that was really due to transient conditions in a properly performing circuit.

Flight test data documented on a similar BIT design indicated that there were no false BIT alarms encountered in 6 months of flight tests. All failure indications were correct.

d. Operator Error Reduction

Operator errors are reduced by the simplicity of the AN/ALQ-XXX BIT operation--pushing the initiate button and reading the indicator lights. Because the BIT routine is initiated with a single command, virtually no instructions can be ignored, and the routine positively identifies the faulty LRU.

The higher failure rate LRUs are located in the readily accessible fuselage; only LRUs with very low failure rates are located in the wings and vertical stabilizer, which are relatively difficult to access. With this distribution, the technician who may be tempted to remove the more readily accessible LRU if he suspects an ambiguity will, in over 98 percent of the cases, remove the correct one. Also there is no requirement for alignment upon removal and replacement of any LRU.

e. Failure Information Storage

A unique feature of the system is the inclusion of an electrically alterable read-only memory (EAROM) in the BIT module of each LRU. The BIT module will provide complete end-to-end LRU test to attribute a fault to the proper LRU. An electromechanical flag fault indicator, mounted on LRU front panels, will produce a visual indication whenever a BIT detected fault occurs.

f. Maximum Organizational Level Replacement of LRUs

All LRUs are replaceable at the organizational level. The ease with which the LRUs can be removed from the aircraft depends entirely on aircraft LRU access. Compliance with specified mounting provisions is a prerequisite to design approval.

Any of the LRUs can be removed individually; removing an LRU to replace another LRU is not necessary; this includes the units in the cockpit control panel. Any LRU can be removed by loosening the screw-type hold-downs. As required, the LRUs will be designed to fit into the existing mounting provisions on the candidate aircraft. The use of

the same mounting features enables the existing handling equipment to be used, which is significant in the case of pod handling. Quick disconnect and scoop-proof multipin connectors are used to prevent maintenance induced failures.

The LRUs in the fuselage weigh less than 40 pounds and are provided with rugged enclosures, handles, and grasp surfaces to prevent dropping. They are mounted on shock trays by sliding into alignment pins that automatically position and connect them to their air plenums. LRUs mounted in the vertical stabilizer weigh less than 10 pounds. No web of cables need to be moved aside to access an LRU. Simple disconnect of cables is accomplished via the LRU front panel.

2. Intermediate Level

a. Checkout and Fault Isolation

The LRUs are constructed to be tested by ATE. Front panel test connectors provide information on circuit status, which in turn permits isolation to an SRU by observation and decision based on logic rather than circuit probing.

LRU self-contained BIT used alone can fault isolate to an SRU with ambiguities ranging from 0 to 8 in 100 percent of the cases. When supplemented by support equipment, the ambiguity approaches 0. Instructions to fault isolate with simple manual equipment (the use of the specified test sets is preferable, but not necessary) are in the form of logic decision trees. These diagnostics, depicted in Figure II-2, were used as a tool to design test points, BIT, and support equipment capability, as well as to form the basis for predicting the fault isolation time. The diagnostics will be contained in the technical manual as well, to enable the maintenance technician to achieve the predicted success in maintenance within the predicted times.

If BIT were not to be used (an Air Force option), checkout and fault isolation at the LRU level can be accomplished via the LRU's input/output connector(s) and test point connector(s). Functional packaging of the SRUs permits isolation to them from observation of LRU-level performance degradation. From this, the responsible function can be identified, and in turn the SRU that is associated with the function. The LRU test points assist in breaking ambiguities, especially where there are two-way interactions between SRUs.

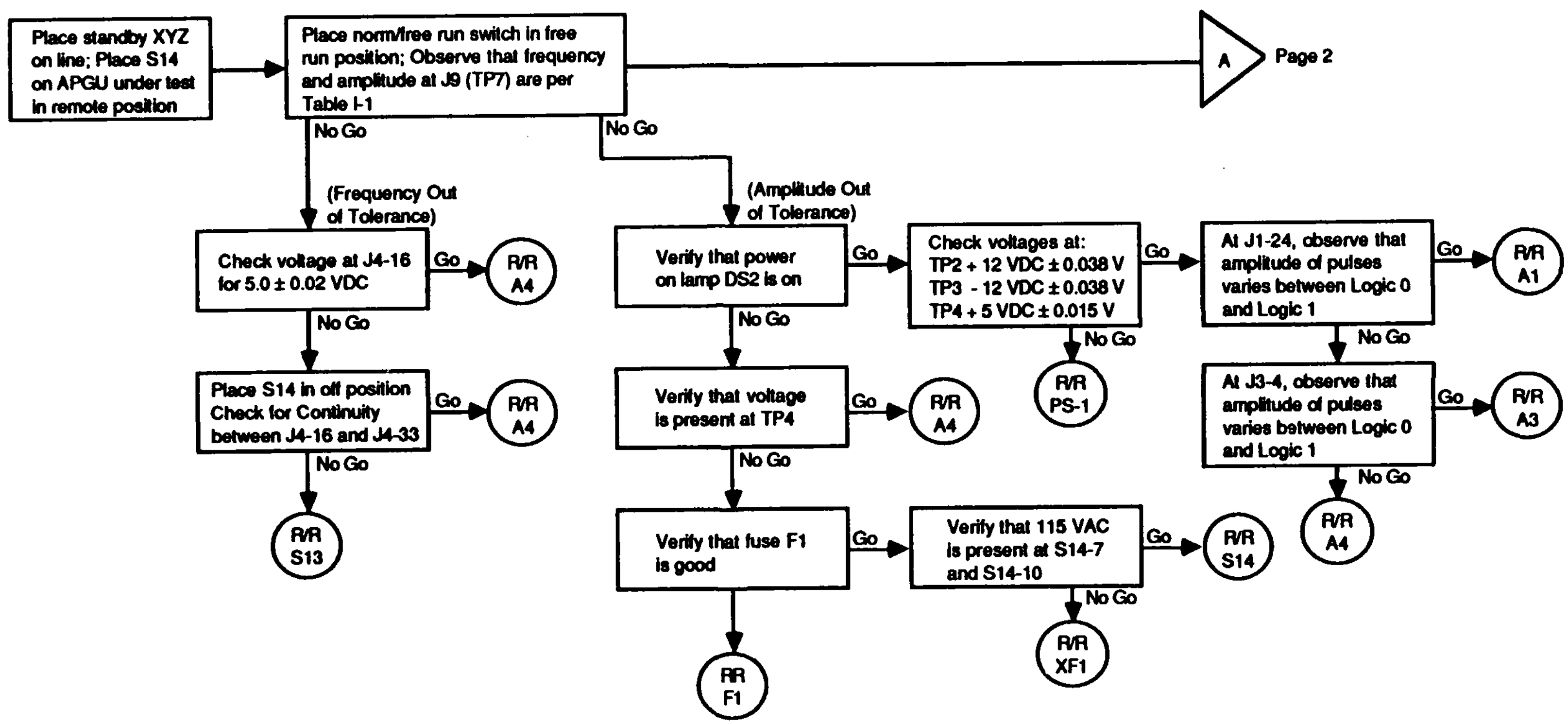

Figure II-2. Sample Logic Decision Tree (Diagnostic)

b. Partitioning of Modules

The boundary of functions within the presently planned subassemblies reflects the goals of minimal interconnections at circuit nodes for ease of fault isolation. Subdivision of the densely packaged digital circuits is also planned. Hybrid technology is used to provide ease of fault isolation into removable, inexpensive subfunctions. (As many as five subassemblies can be replaced by a single hybridized subassembly.) Hybrid packaging also promises that the functional BIT resident on the subassemblies could simplify the test equipment required to fault isolate to the hybrids. Packaging the hybrids into large-scale integrated circuits (LSIs) for additional savings will be the subject of a study during the development phase.

c. Technician Error Reduction

Technician errors are usually caused by improper test set-up and complex test procedures or test equipment. The individual LRU/SRU patch panels in the AN/ALQ-XXX test set preclude improper connection, and the planned use of common, simple test equipment for measurement ensures that the technician is familiar with the equipment. The diagnostics also serve to preclude errors in diagnosis of a problem. On the other hand, if automatic equipment were used, fault isolation would be performed without dependence on the technician.

SRUs are constructed with test points contained in their interface connectors to enable fault isolation to a small group of components without circuit probing. The instructions in the proposed depot technical orders will guide the technician to the faulty component.

d. Remove and Replace

The details of LRU and SRU construction, contained in the technical volume, indicate compliance with the mechanical requirements of MIL-STD-2084. SRUs are all of the quick replaceable assembly (QRA) type, which are accessed by removing a single LRU cover. Digital SRUs are constructed as plug-in PC boards, with the majority as single-layer printed circuits, to reduce cost. Analog circuits are also packaged to facilitate maintenance by using quick disconnect connectors and captive hardware.

Improper replacement is precluded by circuit board keying and the use of different shapes and mounting hole locations for non-circuit board SRUs. Clear connector and cable

markings enable proper reconnection without reference to technical manuals. Circuit board markings facilitate component identification in the same manner.

e. Cable Routing

Cable routing received particular attention in the design phase. Because cable routing is usually first laid out in the actual physical hardware or in mock-ups, from which the cable drawings are made, separate cabling reviews were held, and any problems discovered were adjusted prior to design approval.

f. Maintenance-Induced Failure Elimination

The designs of AN/ALQ-XXX LRUs and SRUs prevent induced failures by eliminating the classic failure causes. Plug-in construction for all but power supplies, regulators, and electromagnetic interference (EMI) filters, which must be solder connected due to current-carrying requirements, precludes damage from soldering except for these latter, low-failure rate items. Guides to prevent mating connector damage assist the replacement of circuit boards. Captive fasteners in LRU covers and most SRUs prevent loose hardware from falling into the LRUs and causing shorts. Exposed terminals are coated with silastic to prevent accidental shorts. Air cooling by forcing cooling air into, rather than out of, the LRUs prevents thermal damage if a cover were left loose.

All SRUs are packaged with components accessible from one side to facilitate their removal. Where needed, transparent polyurethane conformal coatings provide for part identification without removal of the coating. The coating itself is easily removed in local areas and readily patched, thus preventing damage from the alternately required total chemical stripping operation.

g. Technical Complexity

The sophisticated processing circuits justified special attention for support resource planning. As an example, the proposed logic circuits using common buses had a large driver fan-out capability. This requires development of fault isolation techniques appropriate to bus technology to permit compliance with MIL-STD-2084 requirements. Development of these techniques was based on experience with similar equipment, such as the AN/ALQ-ZZZ's Exciter, which also forms part of the AN/ALQ-XXX.

3. Depot/Factory Level

LRUs and SRUs are constructed to be readily repairable at any level of maintenance. With the exception of items such as antennas, transmission-line components, and inexpensive small analog modules (which are discard items), SRUs and sub-SRUs comply with fault isolation to the component level requirements of MIL-STD-2084. This permits SRU and sub-SRU repair at the intermediate level, as with the AN/ALQ-ZZZ. Therefore the repair level analysis to be performed as part of the LSA program would be used to determine the most economical repair with no preempting restrictions.

4. Resultant Design Philosophy

Involving the design engineer in the logistics support analysis (LSA) process results in a continuous design review, beginning in the proposal phase and addressing the dominant support-related technical design and cost drivers. These relate primarily to the BIT, the system division, and the packaging techniques of extremely dense circuits.

The AN/ALQ-XXX was deliberately designed to meet the maintenance philosophy using reliability, maintainability, and LCC analyses as tools to identify and communicate appropriate design requirements to the design engineer. (See Section III.F.)

Building repairability into the equipment results in logistic support cost reduction without noticeably increasing the acquisition costs. Thus, the AN/ALQ-XXX contains only repairable SRUs, with the exception of units that cost less than $100 and have an average failure rate of less than 10 failures per million mission hours.

As the design develops, examination of LRU modularization into SRUs is refined using life cycle cost (LCC) and level of repair analysis for trade-off decisions. LRU test and SRU fault isolation is further examined for potentially greater support cost savings. The alternatives available are fault isolation with ATE, use of manual intervention coupled with ATE to reduce ambiguities, and use of BIT to simplify ATE software. Similar alternatives exist for SRU repair. The design also addresses the skill levels specified in MIL-C-85479(AS). Maintenance of the liquid cooled transmitters is already addressed by the existing transmitter test stations and should therefore not present problems for the AN/ALQ-XXX.

III. SUPPORTABILITY CONSIDERATIONS IN HARDWARE DESIGN

A. INTRODUCTION

1. Background

With the inception of AR-10 (now MIL-STD-2084), Department of Defense (DoD) Directive DoDD 5000.39, and MIL-STD-1388, the majority of supportability requirements were elevated from qualitative requirements and assessments to quantifiable ones. Metrics are continuously changing to more effectively specify and assess compliance with the maintenance scenario and measure the attendant adequacy of design and support resource attributes to fit the identified need. A recent example of this is the introduction of the Integrated Diagnostics concept, an attempt to develop metrics that can be used to assess 100.00+ percent fault isolation. Attempts are also being made to relate analyses such as LCC and operational availability (A_0) to each other, as well as the "Bucks Per Kill" that top level managers must know to determine alternative solutions to a Mission Elements Need Statement (MENS).

2. Basic Problems with Supportability Definition

The official definition of supportability is contained in MIL-STD-1388-1A:

> The degree to which system design characteristics and planned logistics resources, including manpower, meet system peacetime operational and wartime utilization requirements.

This complex definition has caused much confusion because there are four distinctly different parts to it. One part encompasses the system design attributes and another how well the planned logistics resources can support the system design attributes. These two in turn are multiplied by peacetime and wartime considerations. The MENS usually states a war-fighting need for a weapon system that may require two different sets of support resources to economically support peacetime operations and provide the surge

capability needed in a war. (Even though economics are a major consideration in peacetime, availability, dependability, and capability are prime considerations in time of war.) Both sets of support requirements are rarely considered in a specification.

Another problem with this definition is the phrase "the degree to which." Presently no single metric exists for stating the degree of compliance. Instead, the system design attributes are measured in terms of reliability-associated metrics, maintainability-associated metrics, and testability-associated metrics. Logistics resource adequacies are assessed indirectly by ascertaining their ability to perform the testing and other required maintenance actions via an Aerospace Ground Equipment Requirements (AGERD) analysis, Qualitative and Quantitative Personnel Requirements List (QQPRL), and other analyses as specified in MIL-STD-1388-1A.

This chapter addresses only the supportability issues concerned with design attributes. The stages of the design/acquisition process are described and the supportability factors that are addressed by the government and contractor at each stage are detailed.

B. DESIGN/ACQUISITION PROCESS DESCRIPTION

The design phase begins for the government when performance requirements are matched to a MENS. Though contractors may be involved in this process, they may or may not be the system developers with substantial hardware design experience. In actuality, therefore, the contractor's design process starts during the proposal phase. It proceeds through changes dictated or discussed in the negotiation phase, and continues through detailed design and development, manufacturing, and field change incorporation, as shown in Figure III-1. The boxes in the figure are delineated in Figure III-2, which depicts the activities during the proposal phase. The numbers in the blocks on the figures are work breakdown structure numbers, which are used to control the work, assign responsibilities, and audit progress and cost. All contracts require a work breakdown structure. Table F-1 in Appendix F lists the first four levels of indenture of the work breakdown structure for the AN/ALQ-XXX.

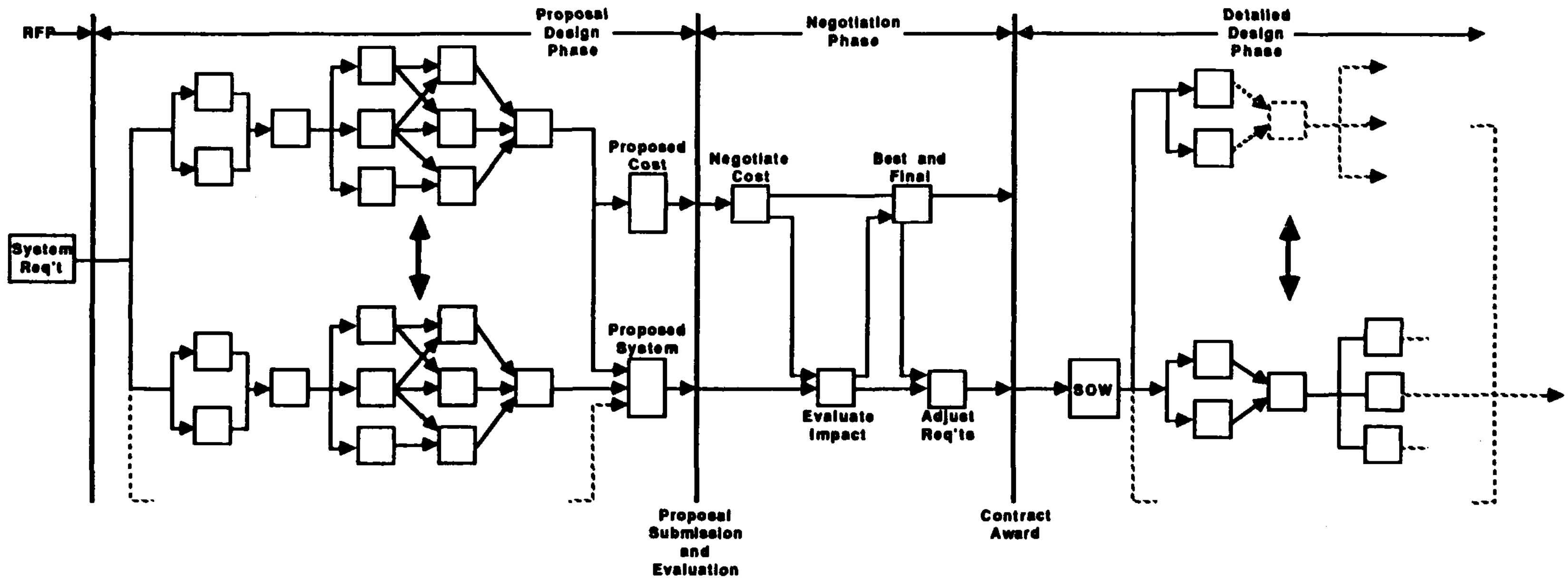

Figure III-1. Design Phases, Overview

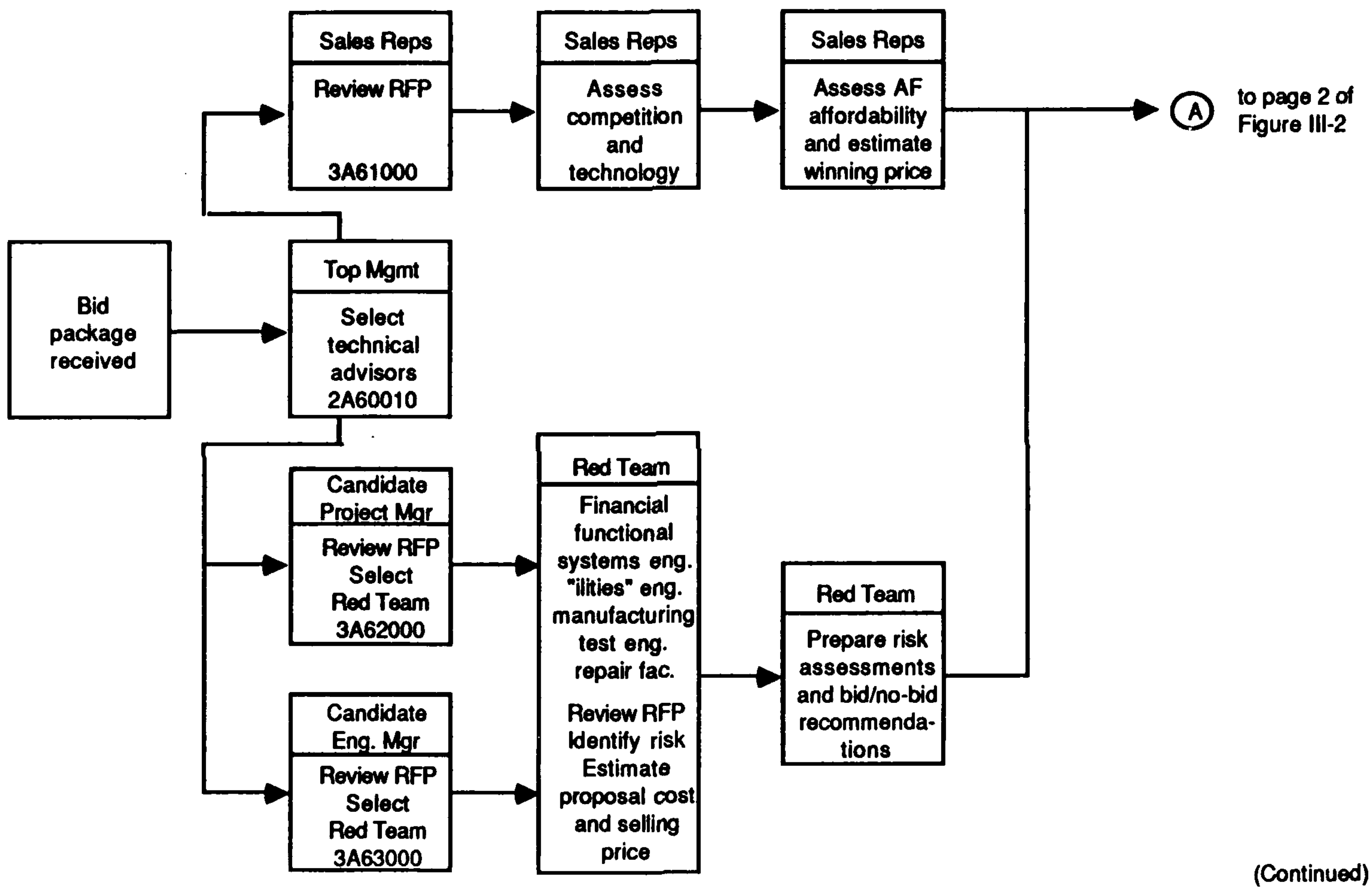

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Figure III-2. AN/ALQ-XXX Procurement Cycle, Proposal Start-Up

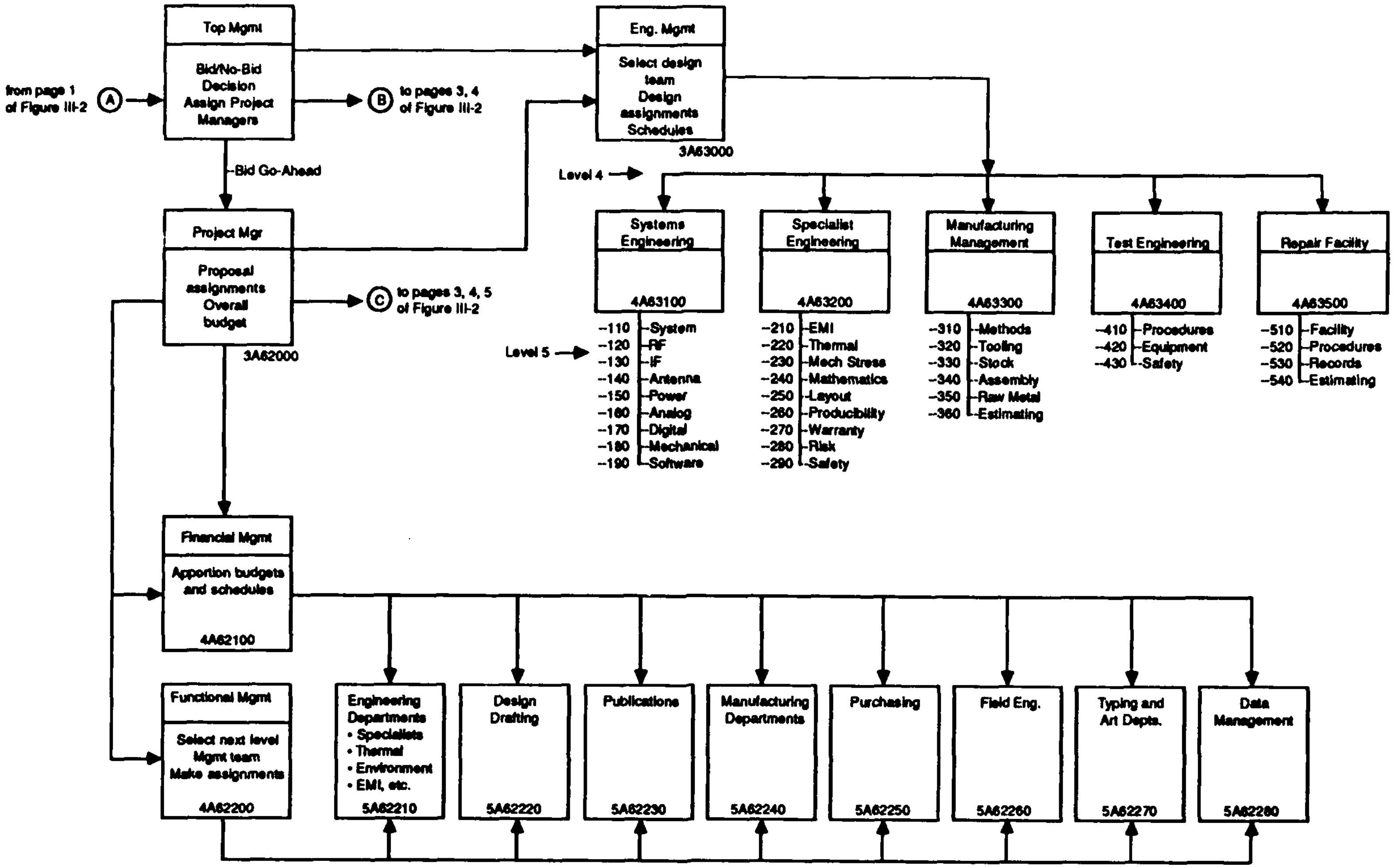

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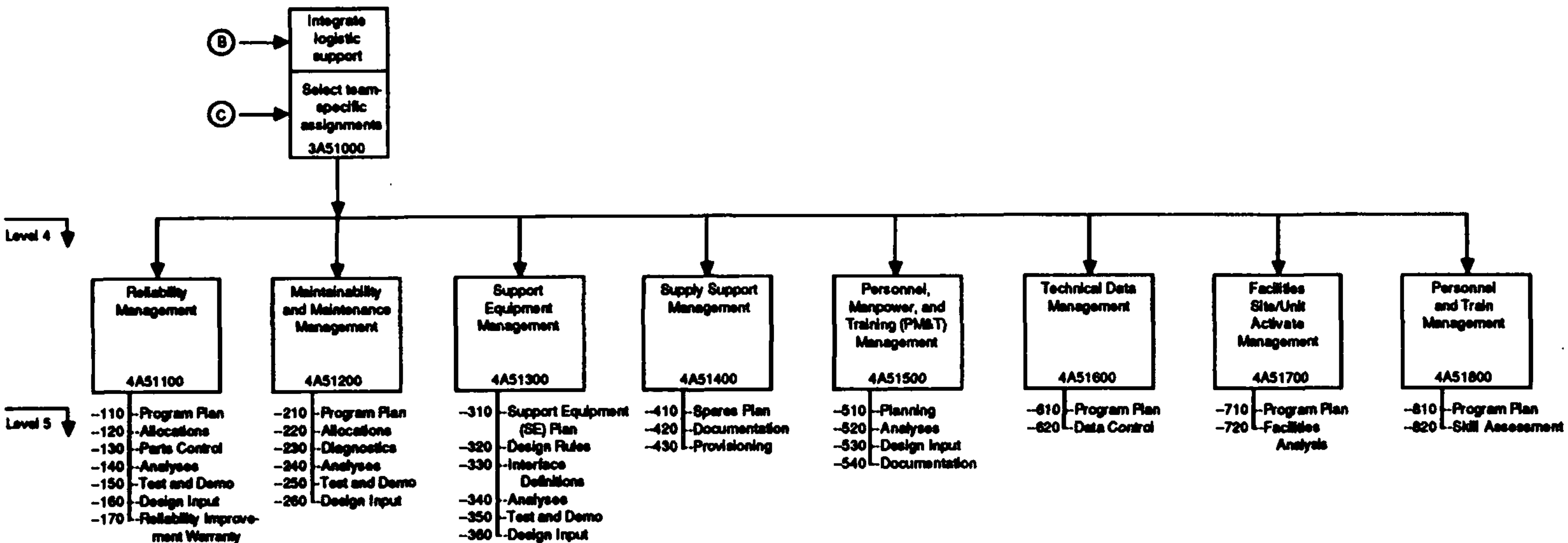
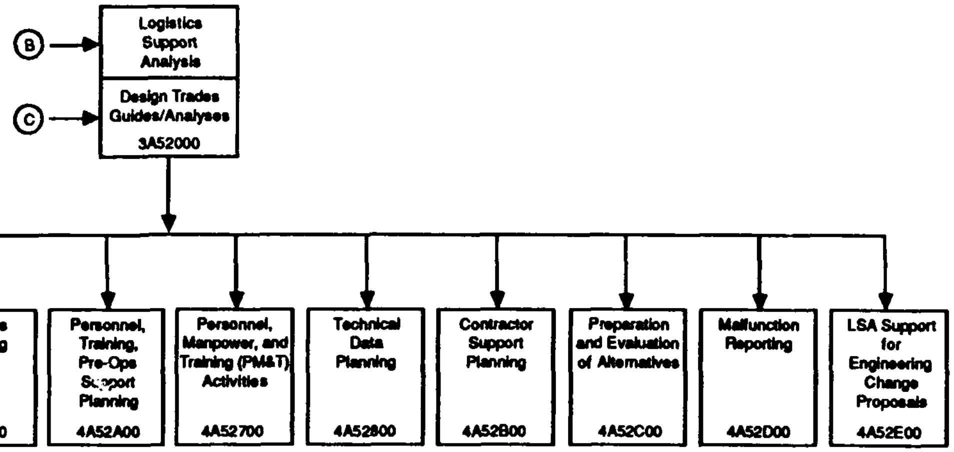
Figure III-2. AN/ALQ-XXX Procurement Cycle, Proposal Start-Up (Cont'd-2)



(Continued)

Figure III-2. AN/ALQ-XXX Procurement Cycle, Proposal Start-Up (Cont'd-3)



NOTE: For level 5 activities and interactions see pages 5 through 9.

(Continued)

Figure III-2. AN/ALQ-XXX Procurement Cycle, Proposal Start-Up (Cont'd-4)

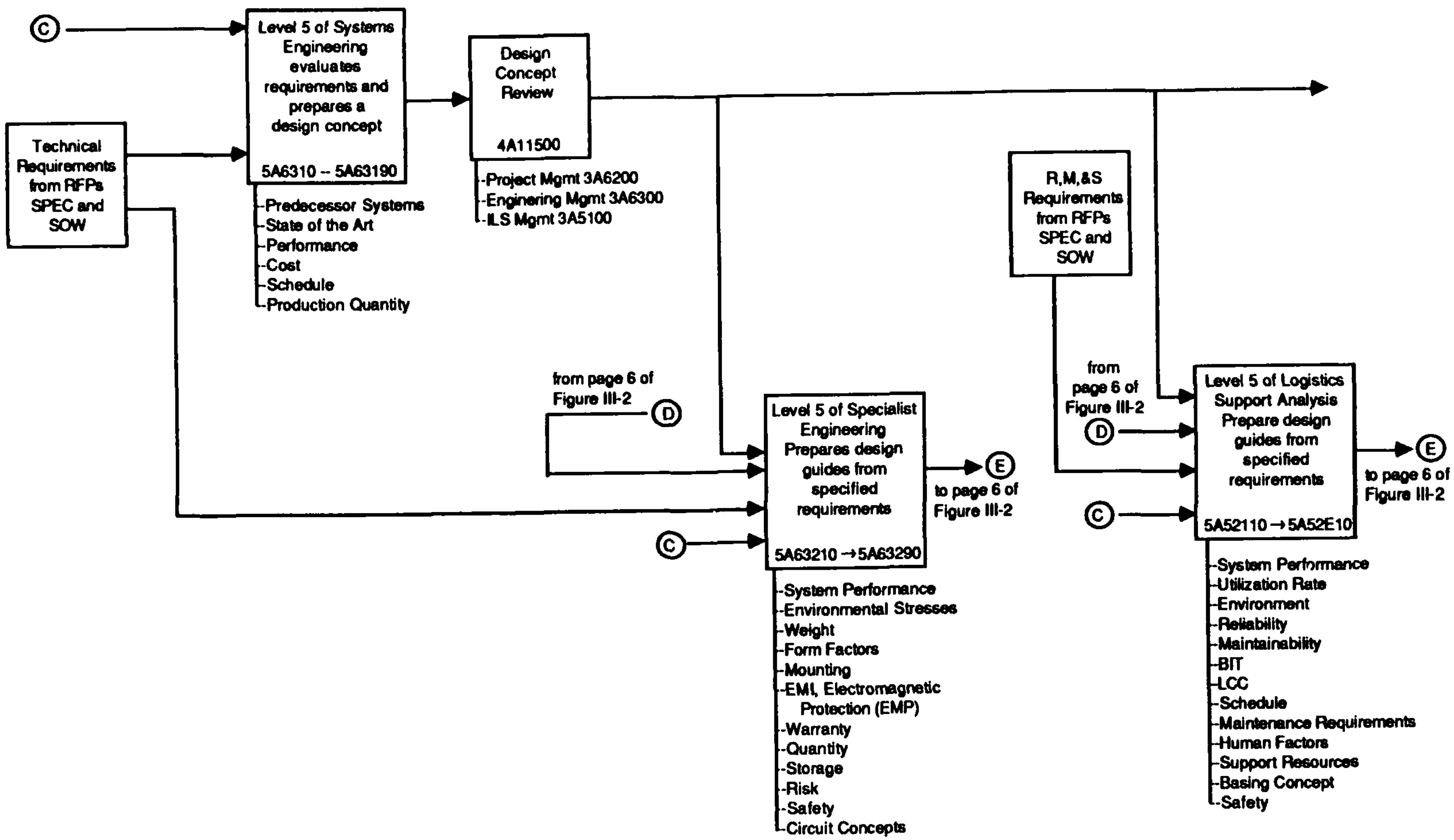


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Figure III-2. AN/ALQ-XXX Procurement Cycle, Proposal Start-Up (Cont'd-5)

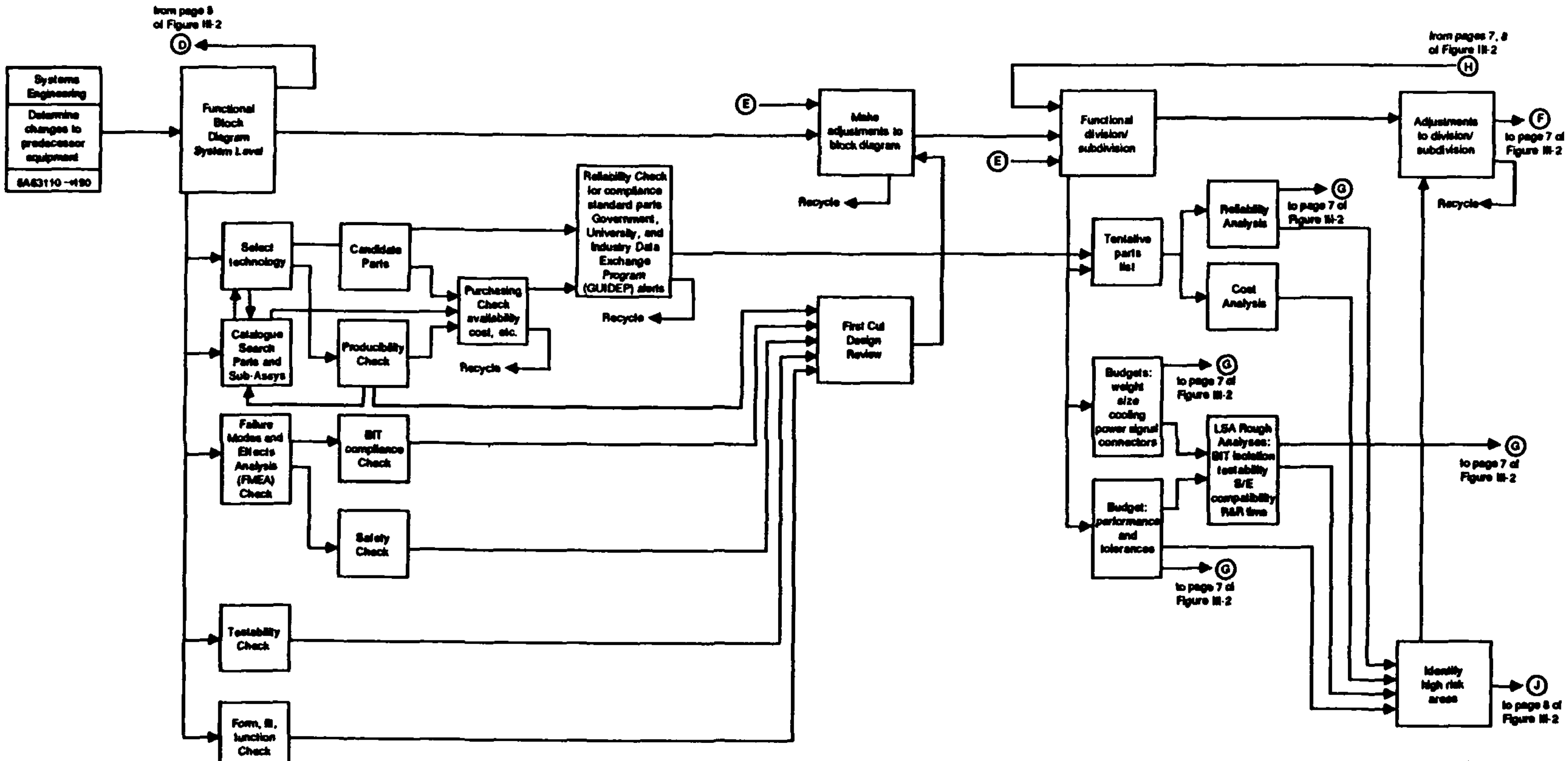

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Figure III-2. AN/ALQ-XXX Procurement Cycle, Proposal Start-Up (Cont'd-6)

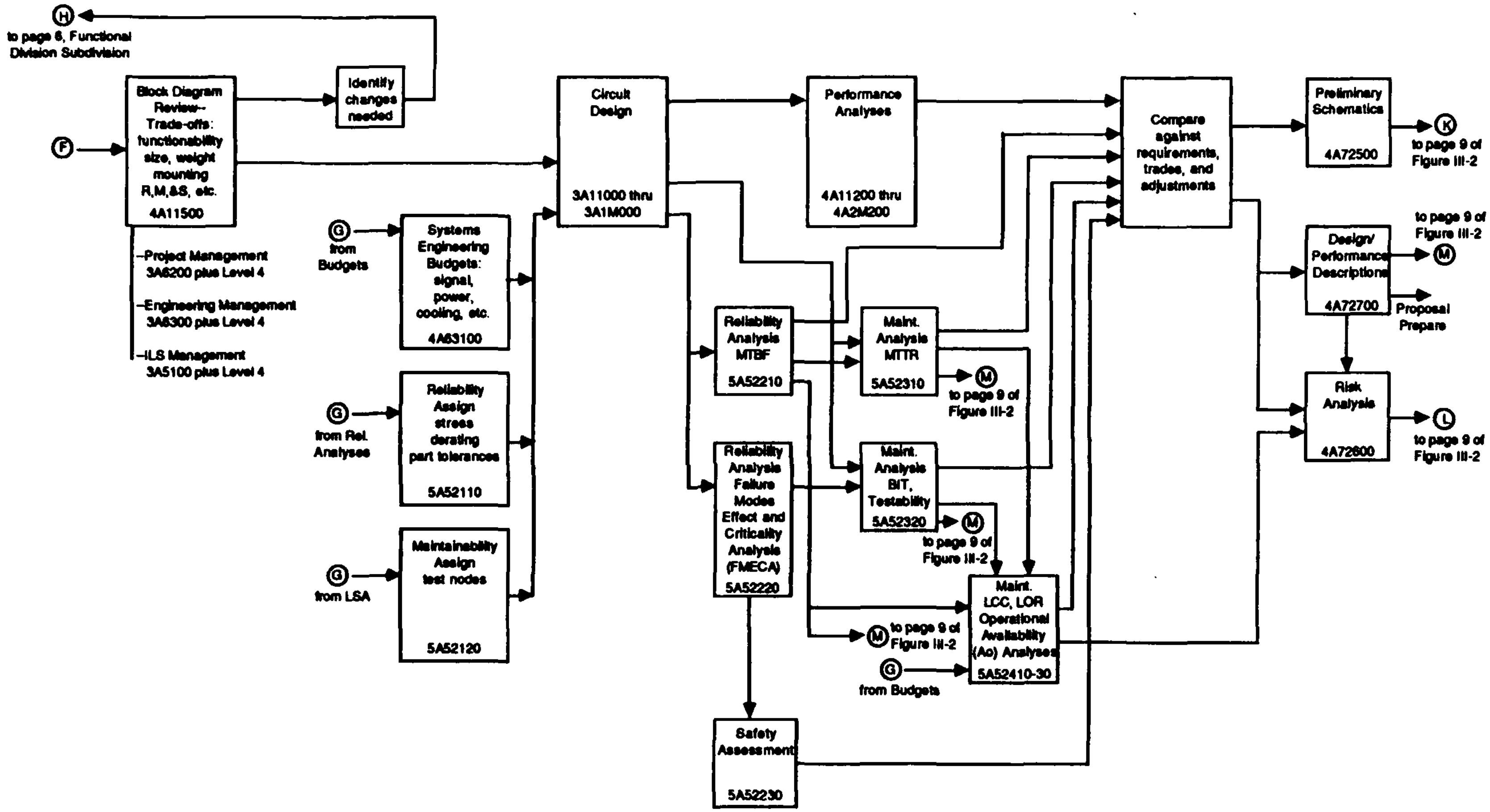

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Figure III-2. AN/ALQ-XXX Procurement Cycle, Proposal Start-Up (Cont'd-7)

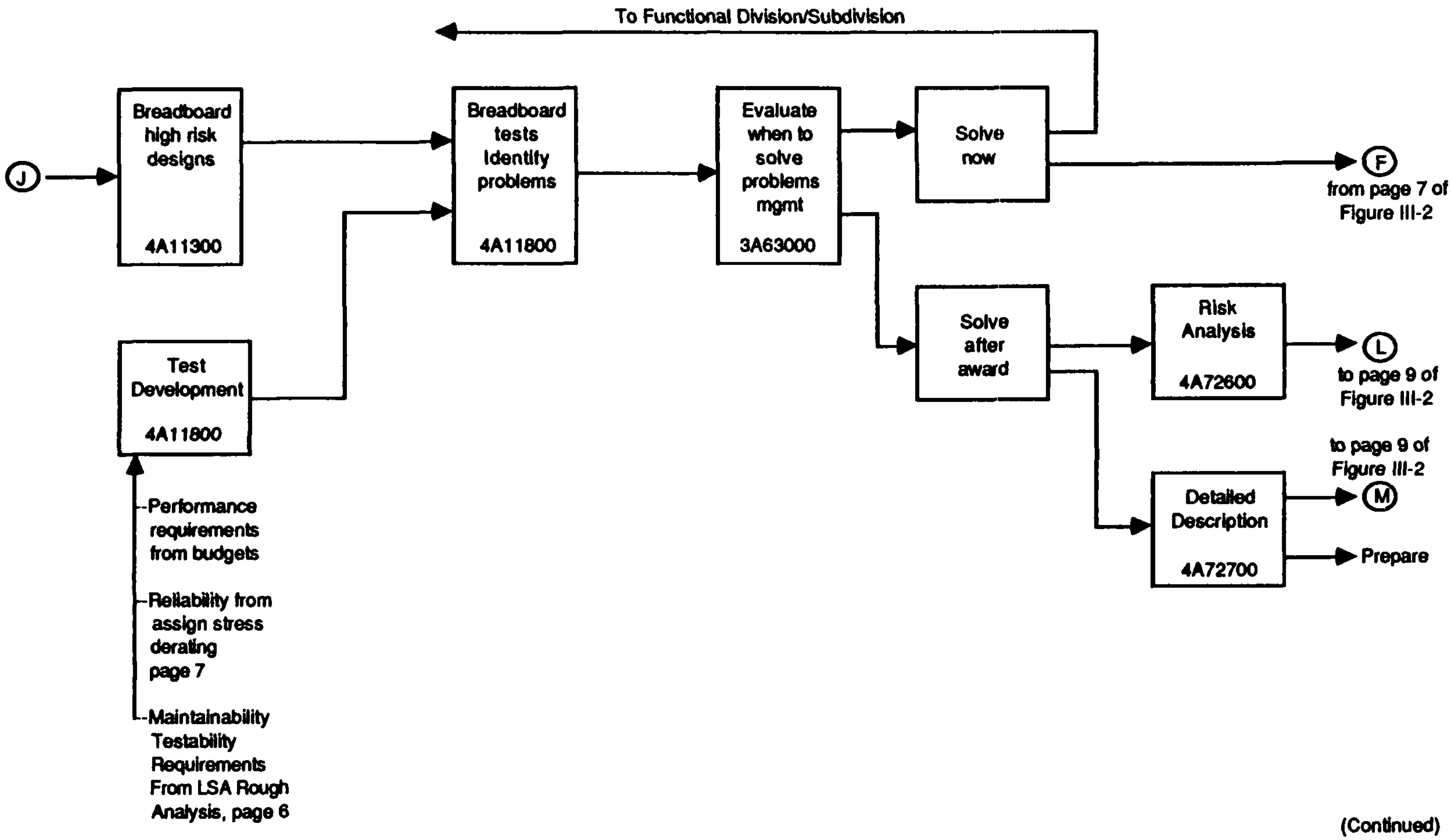

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Figure III-2. AN/ALQ-XXX Procurement Cycle, Proposal Start-Up (Cont'd-8)

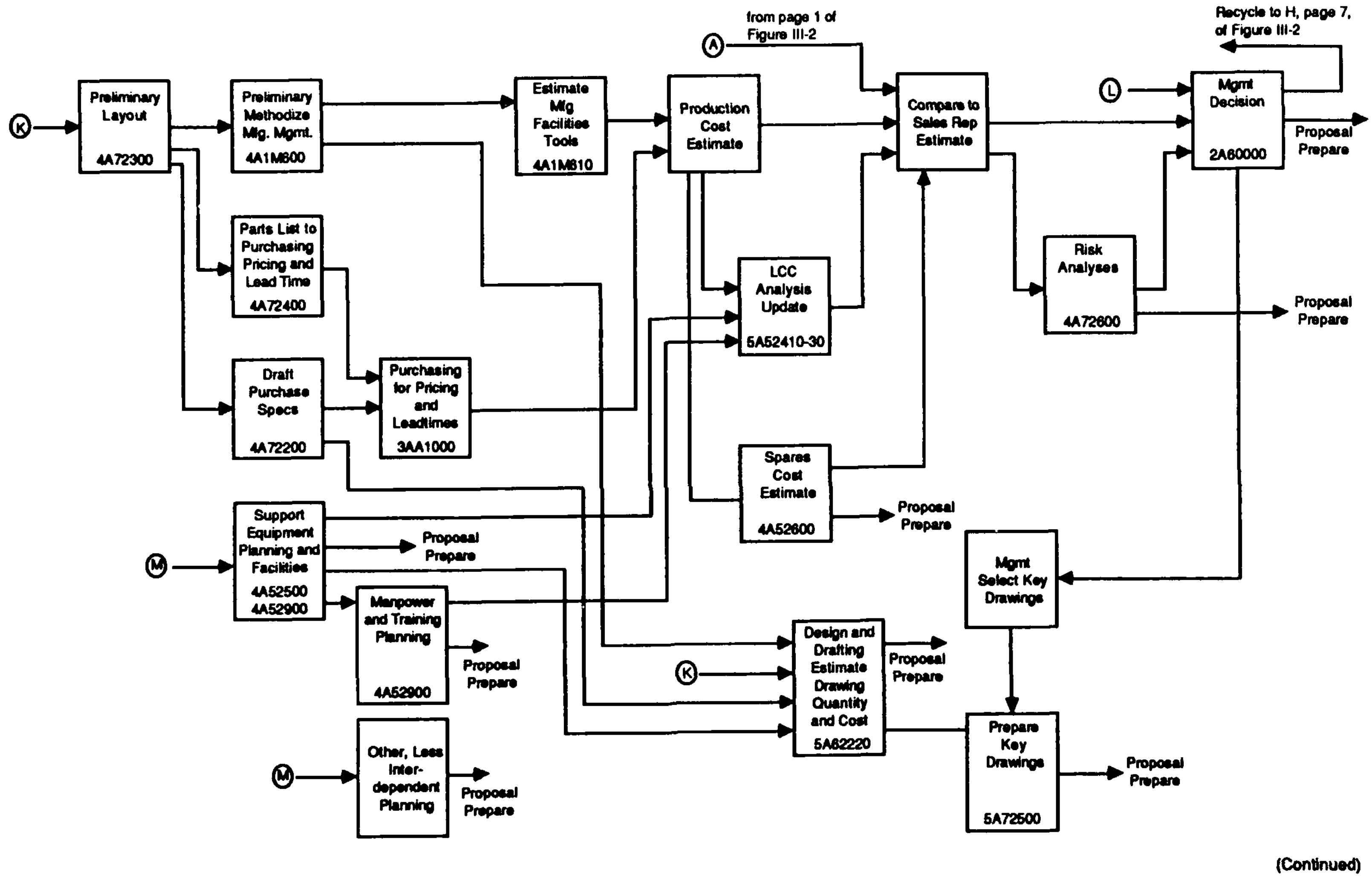

Figure III-2. AN/ALQ-XXX Procurement Cycle, Proposal Start-Up (Cont'd-9)

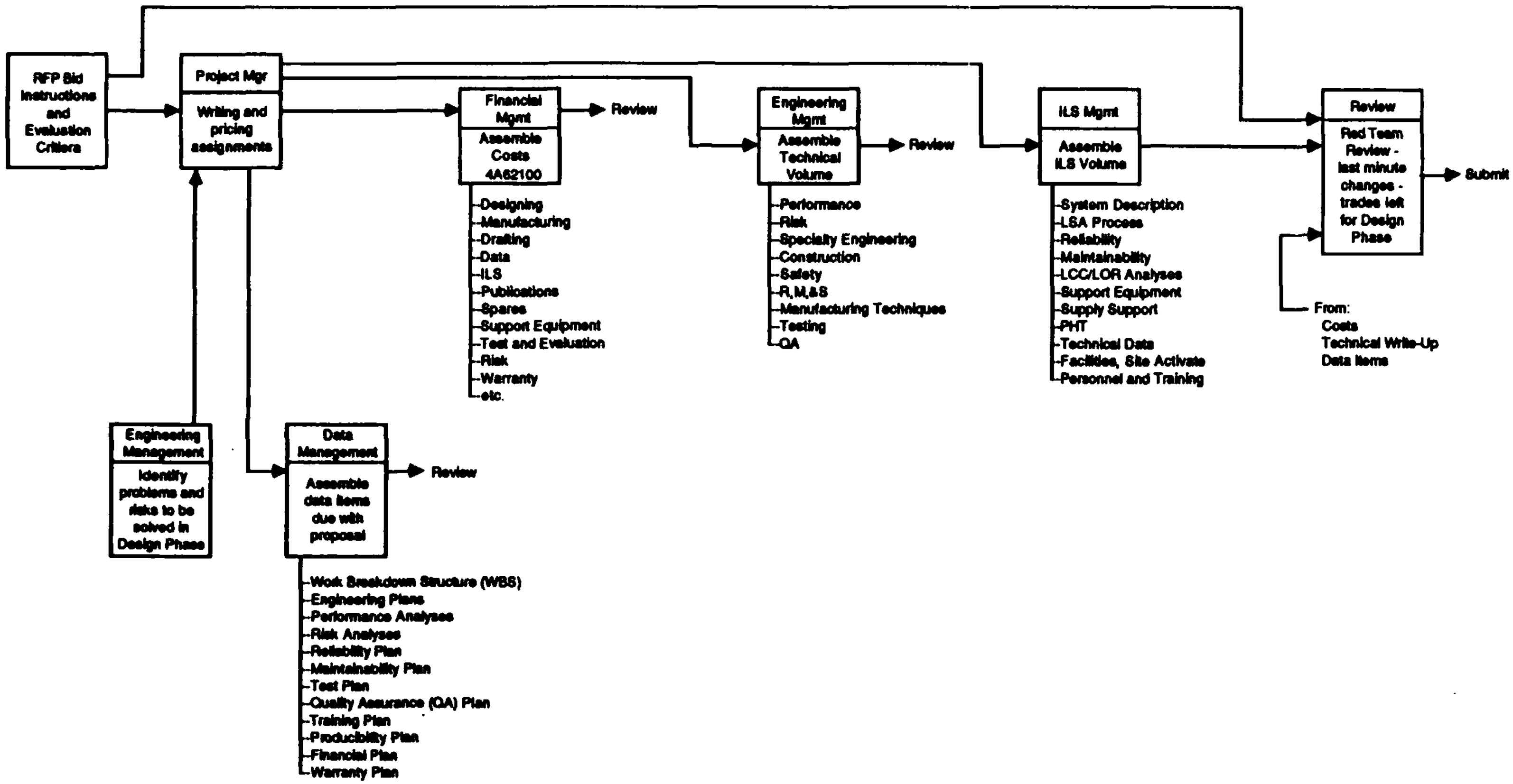

Figure III-2. AN/ALQ-XXX Procurement Cycle, Proposal Start-Up (Concluded-10)

The proposal evaluation and negotiation (Best and Final) phase follows the proposal phase. The price negotiations often adversely affect supportability-related data and design features, because these are considered less important than performance-related ones. The AN/ALQ-XXX was no exception; BIT-dedicated memory and attendant software were eliminated to cut costs. Many support-related data items were deferred to the production phase to save development costs.

The detailed design and development phase includes similar activities as those shown in Figure III-2 for the proposal phase, but concentration is on designing the items remaining from the proposal phase and items requiring changes due to negotiations. During detailed design and development, however, there is no decision about bidding to be made, and the costs are all known. Drawings are prepared, as are other data items, and the manufacturing processes are carefully scrutinized for tolerance buildup and compatibility with the design features. Design changes may also result from the preparation of drawings or the scrutinizing of the manufacturing methodology.

Data move from one discipline to another, usually in serial form. In the design process, the data flow begins with the specification. However, for purposes of analyses, the information pertaining to an analysis must be at hand before it can be performed. For supportability analyses, a set of necessary and sufficient information about the design is needed. Reliability analysis requires a parts list and knowledge of the environment. For maintainability analysis, reliability figures, knowledge of how an item is constructed (for calculating task times), and knowledge of performance (for calculating metrics associated with fault detection and fault isolation) are needed. Table G-1 in Appendix G details the data requirements, their form, and their sources and destinations.

The apportioned values of supportability-related requirements are checked against the results of detailed design analyses to assess compliance with the quality assurance requirements of a contract or of internal corporate procedures, whichever are more stringent. These data are input to the formal design reviews of each item designed, to the lowest level of assembly, including purchased assemblies and subassemblies. Compliance is prerequisite to design approval. While reapportionments are made, the reapportionment cannot compromise overall system requirements.

1. System Specification

The AN/ALQ-XXX's performance requirements were derived from an identified need to counter new threats in the electronics warfare domain, which the predecessor equipment, the AN/ALQ-ZZZ, could not handle. This is the customary genesis of new electronics systems; they are usually an upgrading of capabilities or a redesign to employ new technologies or to fit into a new vehicle.

In this case, the AN/ALQ-XXX was to fit into the same airplane, replacing the LRUs of the predecessor equipment in form and fit. The new functions are thoroughly described in the technical portion of the specification, following the format specified by MIL-STD-490. Teams of government and contractor systems engineers develop the details of the performance requirements in a pre-proposal phase. The contractor personnel are usually chosen from potential bidders, who either team with the government or have the opportunity to critique and modify the government's requirements before the specification is finalized. The latter was the case for the hypothetical AN/ALQ-XXX--its pre-proposal phase of the acquisition cycle lasted nearly a full year.

The typical quantitative supportability requirements from the predecessor equipment, described in Chapter II, were included in the AN/ALQ-XXX specification. These requirements are rarely changed from system to system because they are derived from sample statements contained in acquisition guidance documents that each Service/Service branch has. Reliability requirements changed to remain commensurate with the state of the art in component technology, but the support equipment was specified to be the same as that for the predecessor equipment. In addition, the supportability requirements included evaluation criteria that would force a contractor to make every effort to exceed rather than simply meet the requirements. These criteria, A_o and LCC, are discussed in Section III.D.

The specification also defines the techniques of proving compliance with specified requirements. For reliability and maintainability of the AN/ALQ-XXX, the analyses contained in the SOW and data item descriptions (DIDs) and formal demonstrations were required. A testability analysis was also specified. No other supportability analysis nor demonstration was specified.

In addition to the system reliability, maintainability, and ILS specifications, a large number of subordinate specifications are cited, usually tailored with the caveat "to the

extent specified herein." These in turn contain their own subordinate specifications, which are left for the bidder and evaluator to interpret. Many of these specifications conflict. At the very least, the degree of design detail specified leaves little design freedom regardless of which design or manufacturing attribute is addressed. Appendix H lists typical specifications contained in RFPs and contracts.

2. Request for Proposal Requirements

The RFP contains the performance specification, pricing requirements, delivery schedules, an ILS specification, applicable government-supplied metrics, an SOW, and instructions to the bidder.

The SOW defines how the work is to be performed (for example, organizational structure, required work plans, proof of performance, checks and balances, work breakdown structure, and formal design review requirements). Formal reliability and maintainability program plans for the AN/ALQ-XXX were required to be submitted with the proposal to identify the organization, authorities, design review procedures, and analytical techniques that would be used. A formal ILS plan was also required, which repeated much of what was contained in the supportability program plans. The RFP also required that supportability formal design reviews be part of the regularly scheduled performance design reviews. This requirement resulted from an innovation during the predecessor equipment design process--the contractor had voluntarily combined these reviews, which had previously been held separately, to gain more effective design control.

The quantitative requirements specified in the RFP require analyses to establish credible proof that the proposed design can meet these requirements. Compliance with technical performance requirements or with supportability metrics is easily evaluated through bidder-supplied results of analyses, or even analyses themselves, which are usually thoroughly substantiated with the design features they are based on. A design is usually based on some predecessor equipment for which previous analyses or sufficient details exist that can be used to perform analyses during the proposal phase. If insufficient information is available, worst-case analyses can be performed using regression techniques for reliability, maintainability, and testability characteristics of a design.

RFP requirements are not limited to describing performance and performance evaluation criteria (such as the quality assurance section's test requirements) contained in the technical portion of the RFP. The RFP also contains a section describing the proposal

evaluation criteria, which can be much more difficult for contractors to interpret. Unlike the performance requirements, which are very specific, the proposal evaluation criteria are usually vague. Because the proposal evaluation criteria are vague, bidders, uncertain of the proof that is being sought, will attempt to provide as much substantiation as possible, in as many different ways as possible, to prove their claims and gain a credibility advantage over the competition. Most RFPs require proof of compliance with reliability, maintainability, and testability requirements by quantitative analyses, and most also require an LCC prediction. Although required for the AN/ALQ-XXX, A_0 predictions are usually not required, since the major portion of A_0 is beyond the control of the contractor. Information about factors beyond the control of the contractor are usually provided by the government in the RFP.

3. Proposal Preparation Process

a. Cost

In preparing a proposal management customarily considers acquisition cost to be top priority. Historically, evaluation criteria were always based on lowest acquisition costs. Although evaluation criteria do at times mention that LCC is part of the evaluation criteria and managers must respond to this requirement, they traditionally will not strive for lowest LCC at the expense of acquisition cost or of performance. Thus, the primary objective of a proposal is to meet the performance requirements at the lowest acquisition cost possible.

The first cut at designing to meet performance requirements will usually not result in the lowest acquisition cost, nor in supportability characteristics that are estimated to be better than the competition's. Therefore, design characteristics are critically analyzed throughout the proposal phase and finally by a Red Team of experts representing all disciplines involved. Design trade-offs are identified that can be used to solve problems that may arise in the actual development phases. Design flexibility available in the proposal phase permits producing a design on paper that incorporates the best features available for the proposed design.

Design features described in a proposal contractually bind both the contractor and the government to the same extent as costs, since contract award is based on acceptance of the manner by which the proposed system is to be designed as well as how much it will

cost. Exceptional care is taken to ensure that the design features described in a proposal will actually accomplish the required performance and that the technology, as well as the specified components, will do the job. An RFP usually specifies the requirements that are inflexible, such as the requirement for the AN/ALQ-XXX to fit in the same location with the same mounting provisions as the predecessor AN/ALQ-ZZZ equipment. This requirement limited the LRU's volume, as well as the number of input and output pins that could be connected with existing cabling. This requirement was inviolable; any proposed changes would have certainly disqualified the bid.

b. Competition and Risk

The successful manager realizes that the competition can meet the same performance requirements with the same or better technology at the same or lower acquisition cost. Risk factors are evaluated in the bid/no-bid decision process to ensure that the considerable effort and investment of preparing a proposal will not be wasted. Therefore during the proposal phase, every effort is made to first attain the performance requirements with a scientifically sound design based on low risk. To do this requires minimum reliance on new technology and maximum reliance on tried and proven circuits from predecessor equipment. The combination of requirements, today's competitive environment, and fixed-price contracting requires that any risk to the contractor be identified and reduced to an absolute minimum, certainly within the risk monies identified to corporate management. This requires that much of the design, especially in risk areas, be completed to the point of assuredness that the item will work when built.

Describing how a design will be accomplished and what the costs will be is not sufficient; credibility must also be established--substantiating as many claims as possible in the proposal is the best opportunity for gaining an advantage over the competition. This requires a detailed explanation of the design of the proposed equipment. A good proposal team will out-guess the competitor and provide a rationale for a particularly important design feature that the competition may have overlooked. Benefits of such a feature will be discussed in detail, especially if it can be shown that it benefits all performance and supportability requirements and does not adversely affect cost or risk.

As many analyses as are feasible within the time limitation are made to prove compliance with or bettering of the requirements. Detailed analyses are made, especially in cases where a broad, cursory analysis reveals that borderline compliance exists. When

these analyses indicate that a risk does exist, circuits are breadboarded and tested, particularly in areas that involve crucial timing, shared memory, and stringent environmental conditions. If worst-case analyses should identify a problem, such as the allocated requirements are exceeded or barely met, the engineering manager is informed of the problem. He or she will either cause a more detailed design to be generated or ask for the apportionment to be rearranged, depending on time and his assessment of the risk involved.

The team must ensure that all trade-offs made will result in the lowest acquisition cost. Generally the competition has equal access to contemporary technology and can deliver comparable performance at the same or lower cost. Therefore, competitive advantages of a particular design are evaluated in terms of higher reliability without reduced performance and lower LCC without increased acquisition and development cost. The discussions of trade-offs and risks involved also provide much needed proof to the proposal evaluators that the design has been thoroughly analyzed, all risks have been carefully weighed, and the best course of action has been taken by an entire design team. These discussions should list the pros and cons of each course of action and the problems remaining to be solved during the development phase. Section III.D describes the trade-offs that were made during the proposal phase of the AN/ALQ-XXX that address these considerations. Reasons for the trade-offs are given to substantiate their credibility.

c. The Bid/No-Bid Decision

Before beginning the design process, the contractor must first decide whether to bid at all (see pages 1 and 2 of Figure III-2). Proposals are very expensive and their preparation costs come out of overhead or profit. The proposal costs, the probability of winning, and the return on investment are carefully estimated. High level management and corporate advisors, the Red Team, are involved in this process. The greater the anticipated business, the higher the level of management and advisors involved in deciding whether to bid. Sales representatives bring estimated selling prices in terms of current affordability to the table. These estimates are considered because they will determine how great the risk is for designing and building to the target price.

The only other factors that may affect the contractor's decision on whether to bid are the readiness of the technology needed to meet the performance requirements, the in-house capabilities, and the contractor's competitive edge in that technology.

d. Proceeding in the Proposal Phase

The next step in the proposal phase is assembling a proposal team (see page 2 of Figure III-2). Assignments are made by the project manager, and proposal budgets are doled out. Most companies have a matrix management organization to maximize manpower utilization, and Figure III-2 shows how such a structure is used in assigning responsibility and budgets. Individual specialty engineering departments, such as Reliability and Maintainability, will assume responsibility through their own managers, who assign work to individuals. These individuals will work as a team with all other assigned individuals under the direction of the project manager. The specialty engineering managers will ensure that the work of the assigned individuals meets the department standards and the proposal requirements. These managers perform individual work reviews and have considerable authority concerning corporate commitment. As the work breakdown structure (Table F-1 of Appendix F) indicates, specialty engineers are at the same level as systems engineers, and the ILS manager is also at the same level of authority as the engineering manager. (This is not unusual in most large companies.)

The specification requirements are carefully reviewed and design concepts developed (see page 5 of Figure III-2). Design guides and performance apportionments are prepared from specified requirements and then tailored to the design concept once it has evolved. In the process many brainstorming sessions are held in which the specialty engineers participate to preclude surprises downstream. Design guides take several forms, but most interpret and tailor the specification requirements to a particular application. For the supportability disciplines, the guides address all requirements enumerated in the LSA and reliability and maintainability (R&M)-related specifications. An example of the translation of requirements for testability into specific hardware-oriented language readily understood by a designer is contained in Appendix D.

After the design guides are prepared, circuits are actually designed and analyzed, components chosen, and manufacturing methodized. These steps are necessary to reduce risk and provide credibility to the customer. Supportability analyses depend on parts choice, pricing and scheduling, and the inspection and handling methods quoted. For high-priced or long-lead items, firm, contractually binding commitments are obtained from sub-tier contractors or vendors.

The individual proposal team members assemble all of the information in credible fashion, writing individual sections and providing the supporting analyses. Draft versions of the proposal are reviewed by the Red Team, who act as proposal evaluators, assessing the proposal's strengths and weaknesses as well as consistency and supporting evidence for claims made throughout the proposal. The Red Team review is usually much more rigorous than the government's review, because a contractor has much more at stake.

e. The Final Phase

The last and final authority is that of the Red Team (as shown on page 10 of Figure III-2). Evaluation criteria, bid instructions, and the target costs enter the team's decision process. Since at that time there usually is no time for proposal recycling, they will make last minute changes, which must then have to be addressed during the design and development phases. These are usually low-risk changes since the Red Team is made up of senior engineers of all disciplines.

C. RFP EVALUATION CRITERIA COMPUTATIONAL REQUIREMENTS

The following paragraphs describe two major analyses, A_0 and LCC, which were RFP evaluation criteria for the AN/ALQ-XXX. These analyses in themselves require supporting analyses; the most critical are reliability, maintainability, test equipment compatibility, test point, and BIT analyses. Together these analyses determine the prime equipments' contribution to supportability. Supportability consists of the intrinsic design characteristics of the prime equipment that require low-frequency maintenance and ensure ease of maintenance. Supportability is governed by the characteristics of the entire support system that facilitate the maintenance of the prime equipment. The support system consists of all assets involved in supporting a piece of equipment, as described in MIL-STD-1388-1A. These assets include the contractor support, spares and repair parts, support equipment, support material, storage and inventory, contractor maintenance, technical manuals, personnel, training and training equipment, packaging, handling, storage and transportation, repair facilities, and data and corrective action systems.

1. Operational Availability Analysis Technique

The A_0 measure is developed from the same inputs that are used for the LCC analysis for those downtime terms involving reliability, maintainability, and usage factors. Other downtime terms are determined from knowledge of the drivers of these downtimes

and calculated from maintenance task analyses that are used to support the MTTR calculations--for example, mean downtime due to outside assistance (MDT_{oa}), at the organizational level. Outside assistance would be required for mechanical tasks, such as removing and installing an overweight LRU. Outside assistance may also be required in fault detection, isolation, and troubleshooting, which are BIT factors. A review of the design attributes for each of these drivers, discussed in Section III.D, provides the basis for estimates of these downtimes.

Other downtime terms are due to the quantity of organizational-level spares ordered and the estimated demand for them. Organizational-level spares recommendations are made during the development phase. The proposal indicates that the recommended spares level will be based on the expected maintenance rates. The analyst must assume that the recommended level will be purchased by the government. Since the calculation includes the fault isolation ambiguity and false alarms allowed for the BIT, the calculation would yield a reasonably accurate downtime if spares purchases match the recommended amount.

The downtime term calculating the time required to obtain LRUs considers the depot-level or intermediate-level turnaround times plus time required for paperwork. These times are the same as those used in the LCC equations and are obtained from the government. Similarly, the requisition time is a government input. The time required to replenish a depleted item considers the lead time quoted in the production portion of the proposal, as well as the spares by lead time that is contained in the RFP (for purposes of quoting escalation cost for spares procurement). These times may not be very accurate but, as may be noted in the operational availability equation which follows, the mean requisition time for depleted spares (F) is one of the largest factors of low operational availability. Every effort must be taken to drive the product containing the term F to zero, because F is usually expressed in days, months, weeks, or years, as opposed to the other terms in the denominator being measured in minutes or hours. Explanation of the terms, as well as the drivers associated with them are found in Table III-1.

$$A_o = \frac{MTBM_{c\,x\,K}}{MTBM_{cxK}+MDT_s+MDT_{oa}+MDT_{ops}+MDT_t+MDT_d+MDT_{or}+[AxCxDxE+\{(1\text{-}CxD)xF\}]}$$

Table III-1. Operational Availability Drivers

SYMBOL	DEFINITION	DRIVER(s)
$MTBM_c$	Mean time between corrective maintenance. Consists of	
MTBF	• Mean time between failures	Reliability, quality, environment
	• False alarm rate	BIT design, performance tolerances, unforeseen environmental effects
	• False squawks	Operator error, unforeseen environmental affects
	• Maintenance-induced failures	Flimsy design, difficult maintenance
K	Usage factor = available hrs/year/operating hrs/yr	Sortie rate, warm-up time, checkout time, other on-ground time
MDT_s	Mean scheduled downtime	Design-driven need for scheduled maintenance, policy-driven need for scheduled maintenance.
MTTR	Mean time to repair	MTBF, fault detection time, fault isolation time, repair time, recheck time, fault isolation errors
MDT_{oa}	Mean downtime due to outside assistance	Inadequate BIT, need for support equipment, maintenance difficulties
MDT_{ops}	Mean downtime due to squadron operations	Maintenance features, Air Force policy
MDT_t	Mean downtime due to training	Maintenance features, BIT
MDT_d	Mean downtime due to documentation	Need for voluminous documentation that is not normally at the flight line, BIT, difficult maintenance tasks
MDT_{or}	Mean downtime due to other reasons	All support related requirements were not addressed in the design or the specification
A	Percent maintenance actions requiring LRUs	Design features for workaround, self-healing, reconfiguring, adjustments
C	Percent LRUs allowed at organizational level	Accuracy of R,M&S analyses and support acquisition planning, Air Force provisioning
D	Percent LRUs satisfied from organizational level	Fault isolation accuracy, false alarms, operator squawks, actual versus planned usage factor, maintenance-induced malfunctions, accuracy of provisioning planning
E	Time required to obtain LRUs at the organizational level	Base operations, paperwork
F	Mean requisition time for depleted spares	Paperwork, procurement cycle, manufacturing lead time, manufacturing to restocking time

2. Life Cycle Cost Analysis Technique

The LCC is developed using the seven equations of the Air Force Logistics Command Logistics Support Cost (AFLC LSC) model (contained in Appendix E) supplied with the LCC model specified in the RFP to calculate some of the support costs. The following LCC equations are used:[1]

C1: Cost of First Line Unit (FLU) (line replaceable unit (LRU))

C2: On-Equipment Maintenance

C3: Off-Equipment Maintenance

C4: Inventory Management Costs

C5: Cost of Support Equipment

C6: Cost of Personnel Training

C7: Cost of Management and Technical Data.

The remainder of the support costs consist of those support equipment costs bid but not included in Equation C5; the cost of management and technical data bid but not included in Equation C7; and the cost of installation, checkout, and integrated test operations. These costs are added to the sum of the seven equations to obtain the total support costs. Total production costs (recurring and nonrecurring) are added as acquisition costs to obtain the total production LCC for the ALQ-XXX. Development costs are usually omitted, as instructed in the RFP.

a. Assumptions

The following assumptions, inherent in the LCC model, are considered in analyses and interpretations of the model results:

- The model considers a uniform level of program activity (such as operating hours) at the base of operation.
- The base spares stock level and depot pipeline quantities are computed to support the peak level of program activity rather than any incremental buildup.
- The model explicitly computes only those logistics support costs associated with the system and LRU/SRU indenture levels. Components below the SRU

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[1] Appendix E, AFLC's *Logistics Support Cost Model Users Handbook*, contains the equations together with a brief description and explanation of the terms used.

level are only implicitly considered by their relationship to repair of a given LRU.

- There is one depot repair location and "M" specified intermediate repair locations.

b. Data Base

The establishment of a data base, as well as the modeling technique and interpretation of the results evolves from an iterative process throughout the proposal phase, where LCC projections are used to develop design innovations and plan support resources. The process of data collection begins by defining the data elements needed for the model, as shown in Figure III-3 . Input data sheets are distributed to the responsible individuals, together with instructions pertaining to the range and depth of each data element. Responsibility for data validation against sources resides with the initiator and is verified by the analyst. The status of the equipment and source data is annotated on the collected data to ensure that it reflects the configuration base being modeled. The data contained in this model represent the production configuration.

Once the data are collected, they are formatted to fit into the equations required by the model's instructions. Costs are usually de-escalated to a specified fiscal year's dollars from the proposed price, delivery schedule, and the proposed lot buys. The data are checked for gross errors by adding costs and failure rates of SRUs and comparing the sums to LRU costs and failure rates.

The proper assembly and running of the computer program is assessed with the Air Force supplied sample. This check permits an additional test for accuracy of results by searching for inconsistent results of the output that may be caused by input data keyboarding or formatting errors.

c. Input Data Supporting Rationale

Substantiation must be provided that each data element used is developed precisely in accordance with the requirements of the RFP. Each input data element used in the LCC model is discussed and traced to its origin, to provide an audit trail attesting to its credibility. When analyses are cited as a data base, the techniques used, together with a discussion of the design attributes analyzed, are presented.

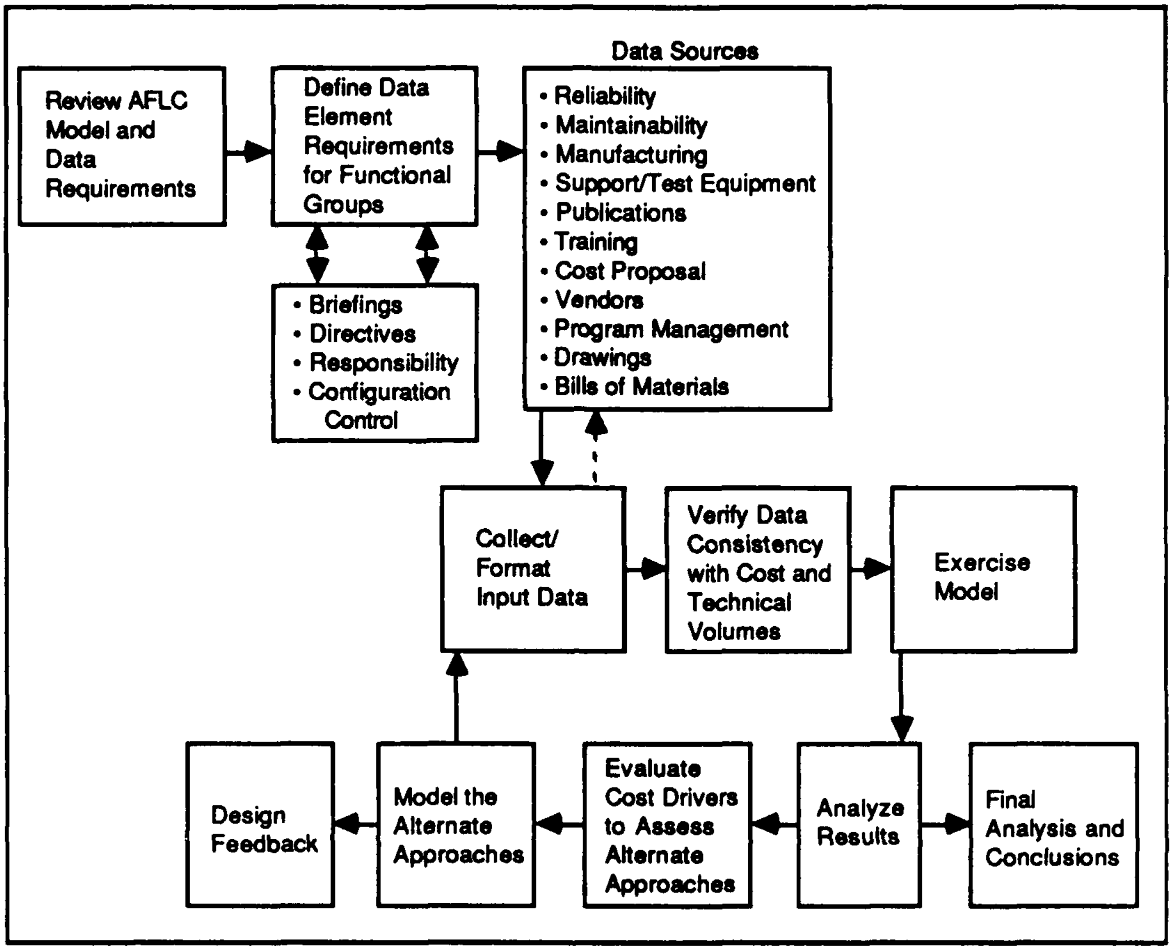


Figure III-3. Life Cycle Cost Analysis Process

The discussions of design-related support cost drivers attest that each design feature is deliberately planned to permit flexibility of support at the lowest possible support cost. (Note the attention that must be given the relation of cost input to the LCC model to the costs actually quoted for the related items of equipment in the Contract Line Item Numbers (CLINs) of the pricing schedule.) Features such as the virtually error free BIT, carefully selected stress-derated components, properly planned test points, and modular functional packaging provide for rapid, precise maintenance. These features support a projection that the maintenance derating factor of 3 to 1 used in the model would prove to be an accurate, if not conservative, Air Force estimate for the mature system. This, coupled with the repairability of the SRUs, including the TWT and its power supply, result in a system with the lowest possible spares and recurring maintenance cost.

The inputs to the LCC estimate model are obtained from the proposed prices contained in the cost proposal and reliability and maintainability predictions, as discussed on an item-by-item basis. The development of the LCC estimate from these inputs is also discussed. The LCC model inputs for the AN/ALQ-XXX are described in Appendix I.

D. RFP EVALUATION CRITERIA INFLUENCE ON DESIGN FEATURES

There are times when evaluation criteria are based on factors that the contractor has no control of, as in the RFP for the AN/ALQ-XXX. This RFP left it up to the contractor to provide reasonable alternatives to the proposed support equipment. Such an option is risky for the contractor because he or she has no feeling for customer preference to the options available or acceptable to the government in meeting the requirement of low LCC, which does involve the choice of support equipment. (The specified support equipment in the AN/ALQ-XXX RFP would not provide the lowest LCC nor provide the highest A_o, as discussed in the sections that follow.) The largest terms in the A_o equation are concerned with support resource availability, which is beyond the contractor's control. However, in the case of the AN/ALQ-XXX, the evaluation criteria indicated that A_o as calculated by the government would be used.

The proposal evaluation criteria forces the contractor to pay particular attention to the drivers of A_o and support cost in his proposal by showing how intrinsic design qualities can indeed affect the elements normally beyond control of the contractor, such as the downtime terms in the A_o equation. By describing intrinsic design qualities (which must be substantiated in the contractor's technical volume), the RFP's proposal evaluation criteria elicited a supportability commitment with specific design features rather than estimated, unsupported metrics.

The following sections describe the design trade-offs that occurred during the proposal phase to finalize the supportability design features of the AN/ALQ-XXX (as obtained from the proposals of the systems it is based on), which provide the inputs into the A_o and LCC analyses. Since both of these analyses depend largely on reliability and BIT, the design features described support these design characteristics as well. Rationale for the trade-offs is also presented.

Two measures for approaching an optimum mix of design features are employed in the trade-offs. One is the requirement to maximize A_o rather than the normally specified inherent availability, A_i. (A_o is considerably more demanding on design features than A_i.)

The second is the requirement to minimize LCC, which places different constraints on design.

The reliability improvement warranty (RIW) cost must also be minimized, but this cost has little effect on equipment design. The RIW cost is more sensitive to the level of assembly warranted than to equipment design, since the MTBF is negotiable before the warranty is priced.

1. Operational Availability

The proposed AN/ALQ-XXX was designed to provide the highest operational availability (A_0) within the constraints of lowest LCC. The ILS team interpreted the RFP's specification and SOW, set objectives, and formulated plans for inclusion of design features for the remaining supportability elements of A_0, to comply with the dictates of DoDD 5000.39. Reliability and maintainability features driven by a design engineer/R&M/LSA specialist team obtained design commitments for high inherent availability for the proposed design. The team had significant influence in BIT design and functional packaging to enhance operational readiness and uptime. In addition, the resultant planning and design of the support resources were based on the most accurate, technically credible source data available. (Table III-1 depicts the major A_0 objectives related to design features, along with the more significant drivers that these objectives are dependent on.)

a. Problem Examination

Examination of the requirements, as well as the objectives, of A_0 (depicted in Table III-1) resulted in specific design guidance in the areas of BIT and modularization. These results were substantiated in the technical volume. LRU installation was identical to the installation of the LRUs in the predecessor AN/ALQ-ZZZ. The combined electro-mechanical design features reduced the downtime terms of A_0, because they did not require outside assistance, additional training, complex decisions, or documentation to maintain the system. Because there were no maintenance adjustments to be made, all maintenance actions were replacement actions, resulting in 100 percent Parts Requiring Maintenance Action (C), in the A_0 calculation. In addition, the solid-state design did not require any scheduled maintenance actions. The foolproof BIT prevents spares depletion due to errors, so that careful spares planning and recommendations could result in Percent Allowed Parts

Satisfied from Organizational Stock (D) to approach 100 percent, thereby reducing the largest portion of downtime to an insignificant amount.

Conceptual or design errors, if not discovered and corrected, also have the potential to increase maintenance rates, due to the added burden of false alarms and false removal rates; they also contribute to induced failure and usage rates. Therefore, in the course of design, failure data for the AN/ALQ-ZZZ low band pod was analyzed to ascertain whether improvements beyond the new antenna, smaller radome, and the new exciter provide an opportunity for further improvements in A_0 and LCC.

Operational Support Requirements. In addition to the organizational level maintainability requirements, there were restrictions to flight line maintenance in the area of available cooling with engines shut, and auxiliary power for the pods (if used as opposed to the optional transmitter tail cap). The LRU and pod handling equipment, any of which would lower the A_0 if maintenance time exceeded the 30-minute ground operations time, were also limited. The optional tail cap would require hangar maintenance for the transmitters. In-flight maintenance was limited to running the BIT and using degraded operation workaround in the event of a failure.

Organizational-Level Restrictions. Examination of the flight line restrictions determined that the BIT must fault isolate properly without the use of the permissible common test equipment specified in the RFP and do so with power off. The BIT flags must be set to unambiguously determine which LRU is faulty. Because antenna maintenance is usually more delayed because of hangar maintenance, the BIT flags associated with the onboard antennas must be located on the easily accessible receiver LRUs, rather than on the antennas. The quality of BIT is a driver of all of the critical design drivers; it is most influential in contributing to operational readiness and dependability.

b. Built-In-Test

BIT relates directly to equipment availability, because maintenance rates increase with an added burden of false alarms. False removals erroneously deplete spares, increase usage rates, and require higher organization level skills and longer maintenance times. For these reasons, BIT on a system level and LRU level must, and are scheduled to, receive priority attention. All related circuits are subject to the LSA process during the design phase. The following decisions were reached early in the proposal development process:

- Exploitation of system operating flexibility by programming the central processor for use as BIT provides comprehensive tests consisting of a complete wraparound test for total processing evaluation, as well as exercising of the various functions generically, with their own performance repertoire. The central processor that controls the BIT also checks itself with a resident program.

- The requirement to receive commands from the RWR dictates an assessment of the operability of the interfaces. The digital techniques used to accomplish this assessment, by comparing received threat data with commands from the RWR, will be further addressed during the development phase.

- The TWT's large contribution to the system failure rate requires that this element be tested as part of the BIT routine; yet radio silence requirements restrict transmission of high power signals. Digital processing has been designed to permit the evaluation of performance with a very small sample of transmitted pulses in wraparound fashion. It also provides for assessing the correctness of timing and other vital characteristics of the output.

- Battle-ready operation places heavy emphasis on BIT self-sufficiency. The proposed BIT routine is a function of programming rather than hardware. It is designed so that it can be performed differently for different purposes. For example, in-flight BIT can wraparound and concentrate on threat tables, while pre-flight BIT can check system vital signs. Troubleshooting subroutines developed by the maintainability engineers will be the basis for the programming, using comprehensive cross-checking diagnostic techniques to reduce false removals. BIT self-sufficiency will be a subject of further investigation during the development phase.

- The two design approaches used for BIT are the primary drivers of A_0 for the AN/ALQ-XXX. One is to design the continuous BIT so that only the items contributing to more than 60 percent of the failure rate are checked continuously, to comply with the requirement of continuously checking simple items with high failure rates, such as power supplies. The second is to develop tests that check all of the performance functions using the same circuits as for the manual BIT but under computer control. In this manner, the true performance or the real malfunction is known, and virtually all of the circuit elements are checked. The computer control/decision process also reduces false alarms to well below requirements.

Other design features were based on the permissible design freedom as follows.

Performance Check. A comprehensive pre-mission BIT routine ensures that the AN/ALQ-XXX is operationally ready. Mission dependability is evaluated in a second

routine, checking all of the mission performance requirements, as described in the technical volume. If a problem is found, it is identified to the operator on the cockpit display and to the maintainer on the LRU display.

Fault Isolation Ambiguity Elimination. The requirement to fault isolate correctly to a malfunctioning LRU for 98 percent of the failures was met, as analyzed during BIT design and reported in the BIT Effectiveness Report contained in the technical volume. Although the failure rates associated with an ambiguity between an antenna and transmitter were low enough to permit its existence, analysis confirmed that the false maintenance actions resulting from such an ambiguity would be particularly troublesome. As a result a BIT subroutine was developed to break the ambiguity. The ambiguity was first discovered in the fault isolating diagnostic that was used to evaluate fault isolation capabilities. The diagnostic will serve to build the fault isolation instructions and BIT repertoire for this purpose. Because all performance functions are accounted for in the diagnostic, those not tested, as well as those not directly isolated, are identified. Feedback to design engineering results in changes to the proposed design, improvements in proposed test techniques, or some combination to resolve the problem. This technique involves the design engineer in the analyses process and provides automatic engineering validation of the detailed BIT routine from which the detection ratio and fault isolation index are calculated.

False Alarm Prevention. False alarms usually occur in a very comprehensive BIT, and they are a major cause of requiring outside assistance or flagging inadequate maintenance instructions. False alarms can be reduced by automatic retest in pre-determined cycles for fault confirmation, resulting in 0.3 false alarms per mission, without operator intervention. Manual retest for confirmation can reduce false alarms to zero. In addition, false alarms can be minimized by avoiding hair trigger circuits that latch up and can indicate a fault due to transient conditions in a properly performing circuit.

Operator Error Reduction. Operator/maintenance personnel error at the organizational level can be due to complex test operations, improper interpretation of results, or lack of adherence to the maintenance instructions. The BIT features ensure that tests are simple and automatically executed, and test routine is beyond the operator's control to ensure that only the proper tests are conducted. Conclusions do not require interpretation and are therefore foolproof. As required, the equipment is all plug-in with standard connectors and mounting hardware readily accessible from the front of the LRUs.

c. Organizational Level Use of Test Points

The placement of test points depends largely on the output of BIT studies during the development phase. The maintainability engineer uses the diagnostics as the basis for analysis, ensuring that comprehensive test point planning to augment BIT, if required, would be accomplished. Organizational level test points for the AN/ALQ-XXX did not seem necessary.

d. Organizational-Level Remove and Replace Actions

The AN/ALQ-XXX's requirement for aircraft installation in the same manner as the equipment it replaced left little freedom of design in aircraft mounting and handling features. At the same time, however, this requirement precluded the need for new handling fixtures, additional skills, training, tools, or support equipment.

Maintenance-induced failures at the organizational level are caused by accidental damage to LRUs (dropping), improper (forced) installation, or accidental damage to interconnecting cables. These failures are minimized by the specified LRU construction and installation considerations.

2. Life Cycle Cost Modeling

The formal design trades performed during the proposal phase involving cost modeling are repeated during the development phases wherever there is doubt about the cause/effect relationship between the design features being traded in the area of production cost, LCC, warranty costs, producibility risk, and effects on scheduling. Program Management develops the factors for production unit costs, producibility, scheduling, and warranty costs. The LSA manager computes LCC, including all support-related cost factors. Any trades made prior to design release or as a function of an engineering change proposal (ECP) action must be approved by the program manager and ILS manager prior to release. LCC analysis was used as an integral tool in the design of the AN/ALQ-XXX. Starting with the mission and program requirements, equipment design features were implemented to minimize the LCC.

LCC is the sum of development cost, acquisition cost of the production equipment in the specified quantity of operational equipment, and the support cost of that equipment. In turn, the support cost is largely influenced by supportability design qualities of the prime

equipment. Table III-2 lists the drivers of support costs related to the equations that calculate them.

a. AN/ALQ-XXX Factors for Low Logistic Support Costs

The largest single factor in the determination of equipment operating costs is the equipment field reliability. This, in turn, is primarily determined by the equipment MTBF. Avionics equipment ranges from spaceborne equipment, with ultra-high reliability parts, part derating, and built-in redundancy that provide years of service with no maintenance, to some of the older avionics systems where MTBFs of 10 hours or less are not uncommon.

The proposed design was aimed at attaining a high MTBF without the cost, size, and weight penalties of redundancies. An MTBF of 450 hours was calculated for the AN/ALQ-XXX using high-quality, screened parts that receive conservative operating parameter derating. All solid-state components were used, except for the transmitter's TWT and tubes used in the high-voltage power supply regulators. The TWT used in the system exhibits an MTBF of 5,000 hours. In addition, the TWT is repairable. The decision to use TWTs, rather than solid-state devices for the transmitter, was driven by design risk considerations of untried technology versus reliability aspects. Liquid cooling was chosen to improve reliability. The use of tubes in the high-voltage power supply regulators was influenced by the same considerations.

In computing the operating costs, the 450-hour system MTBF must be derated to account for failures occurring due to breakage at the operator interface, removal of LRUs that have not failed, equipment mishandling, and similar problems. The Air Force specified a 3 to 1 derating factor so that the MOTBMA is defined as 150 hours for the AN/ALQ-XXX.

To minimize support costs, the MOTBMA must be as high as possible. Eliminating the derating factor is an expeditious means to that end but demands that the maintenance rate approach the failure rate. In addition to BIT fault detection and isolation, human factors engineering is required to minimize maintenance-induced failures and errors. Maintenance-induced failures and errors were minimized in part by SRU packaging trade-offs which yielded increased densities. Because these SRUs contain node-to-node functional division that can be identified by a BIT routine in the LRU, no probing by the technician is required. The attendant reduction of errors, along with the use of plug-in packaging, will reduce technician-induced maintenance actions to the level that corrective

Table III-2. Support Cost Drivers

COST FACTOR	DRIVER
C_1: Cost of spare units	Linearly related for each unit and then all units are summed: • Total operating time over the life cycle • Failure rate • Quantity of like units per system • Cost of unit as a spare • Degree unit is repairable • Replacement spares (percent non-repairable) These costs are added: • Product of number of safety spares and cost • Product of number of rotatable pool spares and cost
C_2: On-equipment maintenance	Linearly related for each unit and then all units are summed: • Total operating time over the life cycle • Failure rate • Repair time • Labor rate
C_3: Off-equipment maintenance	Linearly related for each unit and then all units are summed: • Total operating time over the life cycle • Failure rate • Repair time • Labor rate • Repair material cost
C_4: Inventory entry and supply management	Linearly related for each unit and then all units are summed: • New Federal stock number (FSN) entry and retention cost • Number of new FSNs
C_5: Support equipment	Linearly related for each unit and then all units are summed: • Total operating time over the life cycle • Failure rate • Repair time • Test and fault isolation complexity (e.g., support equipment sophistication/ cost driver) • Support equipment quantity (driven by usage rate and the number of repair facilities.
C_6: Training	Linearly related for each unit and then all units are summed: • Total operating time over the life cycle failure rates and quantity of repair facilities determine the quantity of technicians and training equipment needed • Maintenance complexity determines the course duration • Attrition rate
C_7: Documentation	Linearly related for each unit and then all units are summed: • Total operating time over the life cycle • Failure rate • Time for maintenance and support records • Labor rate The costs of technical orders are added to the costs listed above.

maintenance will be responsible for only a small increase in failure rates over those predicted by reliability analysis.

b. Reliability

Reliability is built into the equipment in an iterative process, starting with the design engineers' selection of proven reliability recommended parts and proper stress derating. Other choices are critically analyzed in worst-case fashion, as are the circuits that evolve, to provide constructive feedback to the design engineer. Once basic performance needs are satisfied by basic circuit design, trades are made to minimize LCC by a combination of reliability and supportability improvement. For the AN/ALQ-XXX proposal, the AFLC LCC model was used to explore the effect of potential changes in high cost driver areas. The resulting configuration reflects careful parts choice, which placed the production configuration at an optimum point on the LCC curve (Figure III-4).

In a highly reliable, easily maintained design, logistic support costs (LSC) can be reduced to a small percent of the LCC, as illustrated in Figure III-5. (Percentages were obtained from the proposals for the systems upon which the AN/ALQ-XXX is based.) Figure III-6 depicts a typical distribution of support cost drivers in a well-designed electronics system.

This encouraging result of LCC analysis was a direct consequence of a simple, yet effective, design with high reliability implementation. The AN/ALQ-XXX was expected to perform with a MTBF of at least 450 operational hours. Using the 3 to 1 derating factor suggested by the Air Force to arrive at the MOTBMA, the mean real time between maintenance actions is only 4.7 months per AN/ALQ-XXX. Thus, it is not unreasonable to expect that the recurring cost of maintenance will be as low as the LCC analysis predicts.

c. Maintenance Problem Examination

Another consideration in the LCC design process is the maintenance philosophy specified by the Air Force. The standard three-level maintenance procedures developed by the Air Force were suggested for the AN/ALQ-XXX program to ensure low risk. It was also requested that the equipment be made compatible with existing depot-level automatic general purpose test equipment. These requests led to a design with extensive BIT capabilities and test points that can be supported in a number of ways. The test equipment could take many forms and, through discussions with the Air Force and further LCC

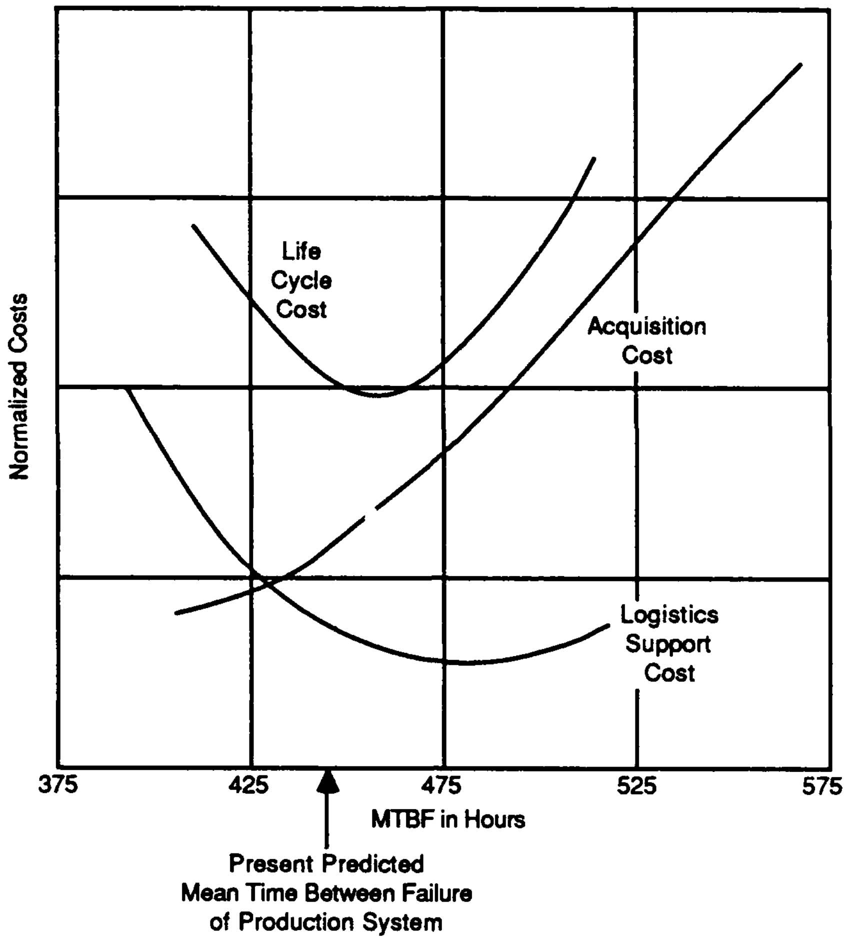


Figure III-4. Life Cycle Cost Optimization

analysis, relatively simple and available support equipment was selected. The following elements were taken into account consideration:

Maintenance Philosophy. The design of the AN/ALQ-XXX did not constrain the maintenance philosophy, permitting the equipment to be repaired at either intermediate or depot level with support equipment ranging from standard commercially available manual to fully automatic equipment. The maintenance philosophy employed in the LCC model, however, adhered strictly to the contractually required three-level system. The organizational level is limited to removal and replacement of LRUs, isolated with only the BIT (with optional support equipment to break ambiguities, if any). The LRUs are repaired at the intermediate-level by SRU replacement. Repairable SRUs are in turn sent to the depot for repair by piece part replacement. Non-repairable SRUs, which are primarily

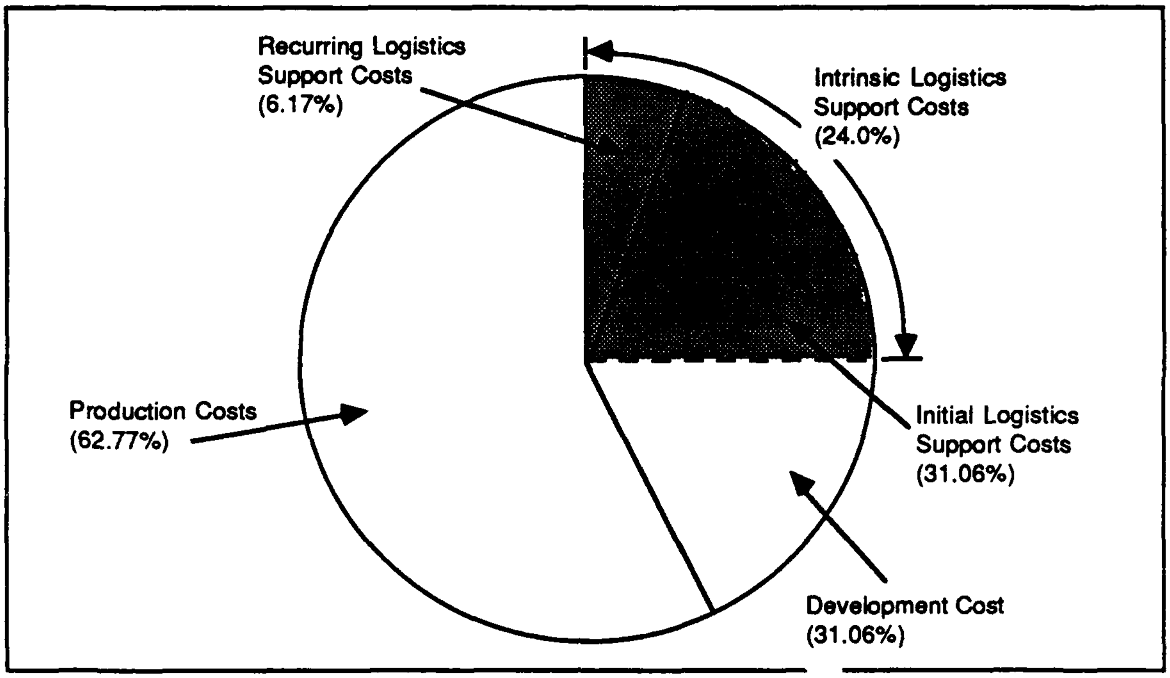


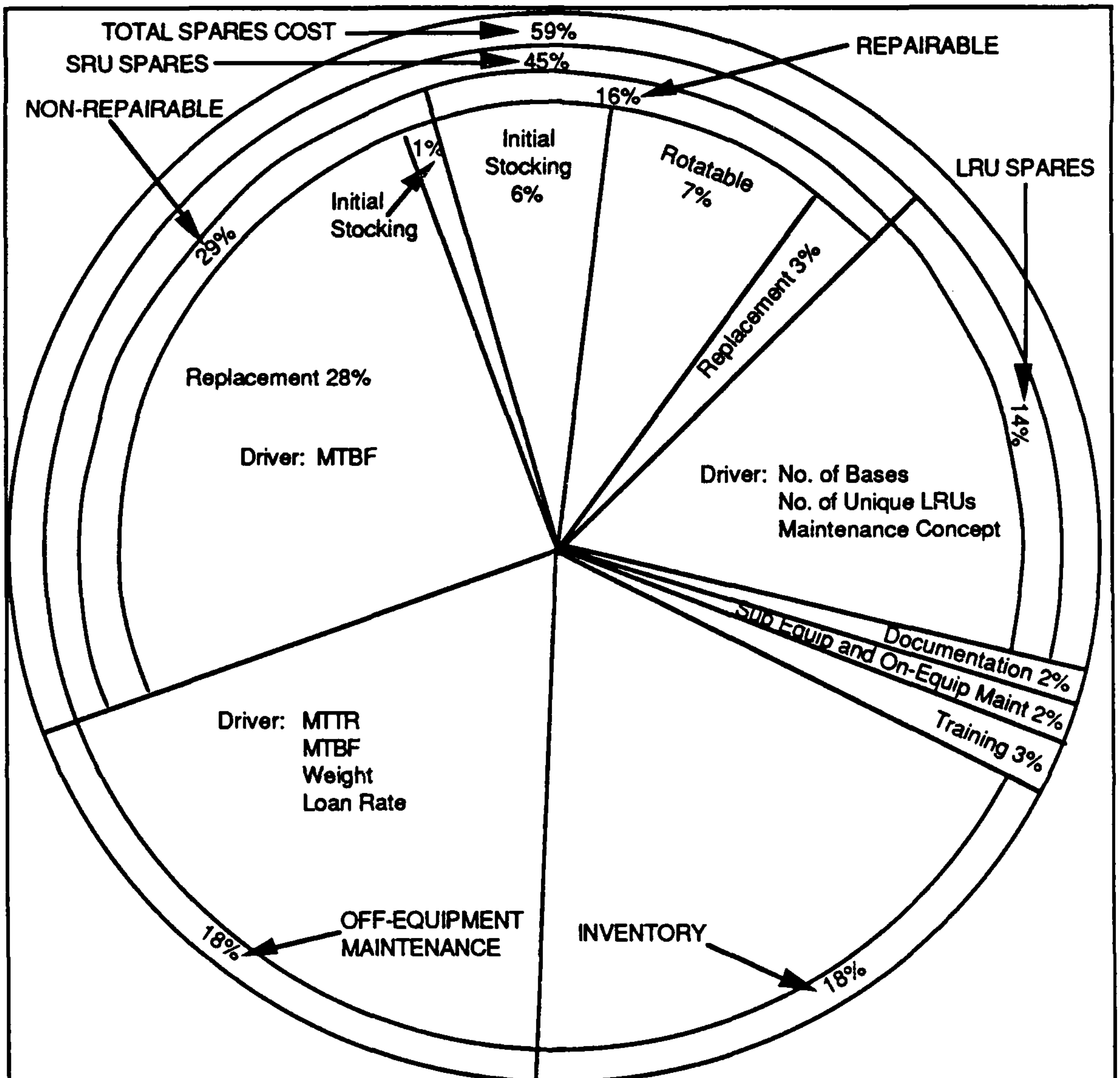
Figure III-5. AN/ALQ-XXX Life Cycle Cost Distribution

LRU chassis-mounted piece parts and form only a small percentage of the population, are discarded at the intermediate level.

Support Resources Requirements at the Organizational Level. In the area of support equipment, only the use of common support equipment as an adjunct to BIT for breaking allowable ambiguities was specified at the organizational level. Selected support equipment uses commercial standard test equipment to lower costs through simplicity, while maintaining flexibility for the Air Force technicians.

Support Resources Requirements at the Intermediate Level. The AN/ALQ-XXX test set was approved for intermediate-level maintenance. The test set is designed to check out each LRU, as well as to fault isolate within an LRU to a malfunctioning SRU or chassis-mounted component. To facilitate positioning and mechanical support of the LRUs during test, a mobile work surface is provided.

Support Resources Requirements at the Depot Level. Initial support costs consist of one-time variable support cost factors required to establish an initial support system. The design attributes that have the largest influence on the initial support costs for the AN/ALQ-XXX are associated with spares and support equipment costs.



System B: Avionics, Electronic
5 LRUs 100% Unique
36 SRUs 85% Unique
5 Non-Repairable SRUs
Total Life Cycle: 10 years
Total Use: 3 million hours

Figure III-6. Typical Support Cost Driver Distribution

The existing depot-level automatic general-purpose test equipment was sufficient to verify proper SRU operation and to fault isolate to a replaceable component or group of components in those SRUs that were repairable. In addition to SRU-related support equipment, intermediate-level support equipment was supplied in the event that LRU

refurbishing, overhaul, or future modifications are required. Therefore, the intermediate level AN/ALQ-XXX test set was approved for depot application as well.

Support equipment costs reflect the equipment that is intended to be purchased, which consists primarily of common and some peculiar equipment housed in a convenient console. The design of the AN/ALQ-XXX permitted a variety of support equipment types to be used for LRU/SRU repair and did not require any special skill beyond that available at a base level. As required, the AN/ALQ-XXX was designed to be supportable by automatic test equipment.

However, the BIT features, which provided fault isolating to the correct LRU for 98 percent of the detected failures, provided information at LRU front panel test points and normal output connections to permit automatic fault isolation to an SRU. These features permitted cost-effective alternate support concepts to be modeled in addition to the basic LCC estimate and were proposed to the Air Force as a cost effective support option.

Spares for the Organizational Level. The AN/AYK-14 computer was specified for use. Its use reduces spares costs, because it is also used as the aircraft flight computer on several other aircraft. Spares costs are further reduced by building in high field reliability. The minimum of one spare LRU and SRU of virtually all types is all that is needed for logistics support at each base.

The ability to use LRUs in the intended fashion on several aircraft without component selection or adjustment is of major concern to the maintainability engineer, who is able to reduce spares projections by multiple applications of the LRUs. This interchangeability is documented in the maintenance engineering analysis for the AN/ALQ-XXX.

Spares for the Intermediate and Depot Level. Spares costs are held low by virtue of low failure rates and the fact that all but four low-cost, low failure-rate subassemblies were constructed to be easily repaired.

3. Reliability Improvement Warranty

The expected repair rate was developed from experience with other failure-free warranty programs and reports on RAW/RIW contracts, such as Arinc's *Guidelines for Application of Warranties to Air Force Electronic Systems*, No. 1500-01-1-1451.

If the desired LRU-level warranty had not proven feasible or cost effective, an alternative SRU level warranty would have been explored and priced. This approach required no increase in support equipment investment at the intermediate level over that of an LRU warranty, based on the anticipated ability of BIT to fault locate to an SRU. The BIT study for developing this capability during the development phase provided the basis for estimating the cost effectiveness of an SRU warranty. Warranty data collection requirements were also addressed in the development of a data collection system in the LSA process. The SRUs considered for this level of warranty were those having relatively high failure rates, greatest cost of maintenance, and greatest return on investment from a continuing reliability program. Two obvious candidates were the TWT and the high-voltage power supply (HVPS). The HVPS is included because of its power regulator tube.

No equipment design constraints were envisioned that would make one warranty level preferable over the other. A decision derived from warranty cost differences and implementation practicality could be made, since a quantitative determination of the two techniques yielded a firm recommendation. The following paragraphs detail the advantages and disadvantages of each option, based on the maintenance philosophy and the design concept.

LRU Warranty. This concept would permit total contractor maintenance, including aircraft maintenance by removal and replacement of LRUs, if desired. No government maintenance personnel would be required at any level, other than for recordkeeping and stock control. The specified elapsed time indicators on the LRUs would facilitate warranty-related data collection. However, the quantity of spare LRUs required to compensate for the normal organizational-level 15-day turnaround would be considerably more than the minimum level for organizational-level support; the LCC model predicts that an additional 22 of each LRU type would be required. On the other hand, if the LRUs were immediately repaired by contractor personnel through SRU replacement, the LRU spares requirements would be reduced, and the cost difference between LRU and SRU warranty would be the contractor field labor costs versus Air Force intermediate-level labor costs (the latter are less expensive).

The possibility of warranty exclusion by virtue of non-contractor personnel damage is at an absolute minimum, and warranty administration is simplest. No change would be required in the spares level and location for discard items, from an organic support, or from

an SRU-level warranty, if contractor personnel assumed the intermediate-level maintenance.

If LRUs were returned to the contractor, SRU spares at the intermediate level would be reduced to zero during the warranty period but that would not offset the costs of additional LRU spares.

SRU Warranty. This warranty could also be managed in two ways. Either Air Force or contractor personnel would fault isolate the malfunctioning SRUs and replace the LRUs with a spare SRU. The extremely simple fault isolation expected by BIT would ensure that the Air Force could fault isolate to an SRU during the warranty period with virtually no investment for intermediate-level support equipment. The details of this concept would be the subject of studies and trade-offs during the development phase.

The principle involved in fault isolation to an SRU was incorporated in the design. It consisted of an electronically alterable read only memory (EAROM) BIT fault storage module plugged into the front panel of each LRU. The EAROM would instantly record the status of each test point reporting to the BIT when a fault flag is tripped. By reading the recorded test point status (with any simple computer), the suspect SRUs could be identified from a look-up table without further testing. Similarly, a repaired (by SRU replacement) LRU could be checked by repeating the BIT in a system mock-up configuration, and obtaining a "GO" from the highly sophisticated BIT, which, by virtue of meeting the required 98 percent fault detection, completely checks every circuit, as described in the technical volume.

This technique would provide the most inexpensive warranty. SRU spares could be provided at the intermediate level in quantities comparable to the organizational level for quick SRU turnaround, thereby minimizing LRU spares requirements. The presently planned 20 hours per month flight program, however, would allow for a 15-day manufacturer turnaround without affecting LRU availability for the flight program. This would permit sparing only the discard SRUs. Disadvantages of an SRU warranty reside in the recordkeeping, credible malfunction reporting, and warranty expiration determination.

Based on these considerations, an SRU warranty seems more attractive than an LRU, particularly if the BIT could be used. The concept would also align perfectly with a contractor maintenance program, such that cost trades made any time before, during, or after a warranty period and based on reliability growth experience could permit switching

from a warranty service to a contractor maintenance program to minimize government investment.

4. Unresolved Problems During Proposal Phase

a. BIT Flag

The requirement to hold the "NO-GO" state of the LRU BIT flag, even if a system restart clears the fault, had to be analyzed further and discussed with the Air Force because this requirement could cause false removals. Alternate techniques of holding the status of a momentary malfunction would be investigated and proposed, if the Air Force agreed. Design flexibility for the decision process was afforded by the fact that BIT status flags are set by the computer as a function of software, which may be readily adjusted to any concept developed.

b. Transmitter Placement

A decision remained to be made early in the development phase on whether the transmitters would be contained in wing pods or a tail cap. This decision would affect performance, organizational-level maintenance, and A_o.

c. Miscellaneous Trades Left for the Development Phase

The following actions were postponed until the development phase:

- Addressing detailed SRU design from a circuit standpoint to fit into the preliminary mechanical layout
- Analyzing test equipment loading needed to be analyzed once the LOR decisions were made, to determine the need for additional support equipment
- Making trade-offs between the introduction of new interface devices versus new support equipment capability to optimize support costs after shop loading had been determined
- Determining trade-offs between SRU spares costs and stocking level versus manual intervention to break AR-10 allowed ambiguities (to single SRUs), to minimize spares costs, particularly where throwaways were involved (integrated diagnostics concept)
- Studying methods to simplify ATE software by using LRU-contained BIT circuits to fault isolate to SRUs to reduce ATE programming costs.

IV. SHORTFALLS IN ACQUISITION REQUIREMENTS DOCUMENTS: FINDINGS AND RECOMMENDATIONS

A. INTRODUCTION

Studies by industry associations (government-sponsored or voluntary) and attendant industry surveys have identified problems in the design process that hinder the delivery of reliable, maintainable, and supportable equipment at the lowest cost. To solve these problems, the integration of the supportability and producibility considerations in the early design stages is being investigated. This solution is being worked in the Unified Life Cycle Engineering (ULCE), the Reliability and Maintainability Computer-Aided Design (RAMCAD), and the Computer-Aided Acquisition and Logistics Support (CALS) programs and similar initiatives, such as those on Concurrent Engineering. With few exceptions, designs are frozen during the proposal phase, where the design and cost commitments are binding; however, during this phase, design costs to the government are lowest. A case study illustrating the extent of the LCC leverage up front in the design process is provided in Appendix A, which contains viewgraphs presented by Mr. Goldstein at an ULCE technical interchange meeting.

As indicated in this study, competition forces the defense contractors to respond to the Request for Proposal (RFP) specifications, requirements, and evaluation criteria with designs that comply with the performance requirements and the quality assurance provisions. Other studies have concluded that if acquisition requirements were changed to include supportability requirements in the proper way, contractors would, by virtue of the fiercely competitive environment, do whatever was necessary to improve their design process to deliver more supportable products. The integration of supportability issues in an ULCE environment would be a necessary step in improving their design process. How the acquisition process could be changed to attain more supportable designs is not immediately clear, however, since a tightening of requirements does not necessarily force the integration

of design disciplines. Some counter-productive acquisition practices are identified in the following sections.

B. SHORTFALLS IN SUPPORTABILITY SPECIFICATION PRACTICES

For purposes of this discussion, supportability implies supportability design features that include the attributes for reliability, maintainability, testability, manpower, and skill considerations, since the problems presented apply equally to all.

1. The Master Specification Forces Segregation

MIL-STD-490, which governs specification preparation, dictates the separation of the performance requirements paragraphs from the supportability-related paragraphs in all attendant acquisition documents, RFPs, proposals, and proposal reviews. Such segregation provides for separate and orderly treatment of each type of requirement; however, the readers of one section of a document do not know the contents of the other sections unless they are forced to read them. It would be beneficial to the goal of ULCE if the performance requirements section, at least, alerted the reader to related supportability requirements. The integration of requirements is not forbidden, even if such integration results in repetition. In addition to the MIL-STD requirements, another reason why performance and supportability requirements are not effectively integrated is technical jargon. Some, if not most, of the supportability requirements are written in terms that do not easily translate into design features, and they are relegated to the specialist for interpretation.

2. Supportability Requirements Are Not Need-Oriented

The recommendation t' supportability requirements be established by the systems engineer or user is contained in both the Office of Management and Budget (OMB) Circular A-109 and DoD Directive 5000.1, *Major System Acquisitions*, although expressed differently in each. These documents state, in no uncertain terms, that the acquisition documents should assert only what is wanted and needed--not how to achieve it. Contemporary acquisition documents, however, attempt to provide a solution without ever posing a problem; this is especially true in the supportability area. This shortfall can be rationalized any number of ways:

- The systems engineer is concerned with performance and has no time to translate performance functions into supportability requirements.
- The systems engineer is concerned only with an operational system and cannot visualize or address failures.
- The supportability engineer has no idea which performance parameters are more essential than others.
- The supportability engineer has no idea how much a performance requirement can be degraded before a part or all of the mission is compromised.

3. Supportability Metrics Are Not Universally Understood

Supportability metrics are considered to be adequate for support planning and support resource acquisition purposes. An exception is the manner with which fault isolation ambiguities are usually specified. Ambiguities should not be allowed, at least at the SRU and sub-SRU levels, since they force the procurement of extra, unnecessary spares. (The problem has been recognized and is being addressed by OSD's Integrated Diagnostics Initiative.)

The application of some of the supportability metrics for design guidance and trade-off purposes engenders a number of problems. Trades among supportability issues involve the many metrics with which they are measured (see Section III.D). These metrics are diverse, ranging from time-related events (MTBF, MTTR), cost-related events (fault isolation ambiguity groups, repair level, repair turn-around times, support equipment loading), and manpower events (task requirements, skill requirements). If automated trades are to be performed among them, then they must all be translatable to the same metric. The trade-off problem is further complicated when the supportability attributes must be balanced with the attributes of performance, cost, and schedule.

Most supportability-related metrics are based on the probability that a maintenance action is required. This concept in turn is based on reliability metrics that employ the probability of failure. Maintenance-action metrics are based on common time and motion studies that result in a measure of how long it takes a person with a certain skill to perform a given action. These measures are also converted to statistics to assess the mean time of such actions.

A design engineer, unless trained in the supportability discipline, has difficulty relating to the supportability statistics, except for parts selection. Even some reliability

engineers are hard pressed to answer the commonly posed question: "Does MTBF apply to one item (one part number with one serial number) over its total life or to the sum of all like items over their total lives?" Regardless of how this question is answered, it is difficult to determine how well an item will perform in a given situation. Statistics such as MTBF only serve to determine spares buys and stockpiling and manpower requirements and support resource loading.

Equally confusing are the statistically based requirements for BIT false alarm rates. Expressed as a percentile, these requirements are open to many interpretations. For example, the BIT requirement is usually specified as being capable of detecting 98 percent of all possible faults, with an attendant table of allowable fault isolation ambiguities and a 0.5 percent false alarm rate. The worst, but perfectly legitimate, interpretation of this requirement is that the 0.5 percent applies to the number of tests performed--that 99.5 percent of the BIT test routines provide the proper answer. Thus, if a thousand tests were conducted per second, a three-hour mission could be plagued by 540,000 false alarms and still meet the requirement.

In meeting the same BIT requirement, a design whose simple but high-failure-rate power supply consumes 90 percent of the system's failure rate could be tested with one or two simple test points. The 8 percent of the failure rate accounted for by the remainder of the system could then be tested by some more complex means. It is not unusual to find that the heart of a system--a digital processor or special purpose computer that has less than 2 percent of the failure rate--can remain untested and still meet the statistically based requirements.

C. SUPPORTABILITY SPECIFICATION RECOMMENDATIONS

Based on the preceding discussion, the following general recommendations are made.

- Supportability requirements must be written in terms that easily translate into design features to facilitate integration of supportability and performance requirements.
- Supportability requirements must be established by the systems engineer or user to be need oriented instead of solution oriented.
- Supportability specifications must be appropriately written into the SOW and the quality assurance provisions of a development specification.

These recommendations demand that more effort be expended in specifying performance requirements. Acceptable performance tolerances must be clearly stated, along with what the system must do when those tolerances are exceeded. The requirements must specify what excursions are tolerable upon mission start-up and throughout the mission, including action and reaction statements. For example, in a tail warning radar, the identification of a threat and the potential warning of a kill is life essential. If the detection range were specified as 200 miles for a particular missile and reaction to the threat required the equivalent time (in terms of closing speed) of 3 decibel (dB) of radar range, the specification should state that a 3dB degradation of radar range, transmitted power, or degraded sensitivity must alert the pilot to take specified evasive maneuvers.

To ensure that systems meet such essential requirements, preparation of requirements documentation requires a great deal of effort from the systems engineer, but enhanced design environments are being developed that will aid such efforts. Acquisition schedules must allow for the time required to properly prepare requirements documentation. By specifying needs in this way, the supportability requirements, formerly understood only by specialists, will be developed to solve the stated problems.

To ensure design engineering and management recognition and support of ULCE principles requires appropriate statements in the SOW and in some portions of the quality assurance provisions of a development specification. Appendix B contains sample specification paragraphs for development specifications for use as a guide to specification preparation. The guide emphasizes quality assurance provisions and ranking of requirements by mission criticality. Appendix C contains sample paragraphs to be used in preparing SOWs.

Appendix A

LIFE CYCLE COST CASE STUDY

IDA

QUESTIONS TO BE ANSWERED

- WHAT DRIVES LIFE CYCLE COSTS?
- WHAT FIXES THE COSTS SO EARLY?
- WHEN ALL NEEDED INFORMATION IS NOT AVAILABLE FOR DETAILED ANALYSES WHAT CAN BE DONE TO IMPROVE LCC?
- IS IMPROVED SUPPORTABILITY AND PRODUCIBILITY THE ANSWER?

HG2

IDA

LIFE CYCLE COST DRIVERS

THE BIG SWINGERS

(THESE FACTORS ALSO MAKE COMPARISONS DIFFICULT)

- **SYSTEM QUANTITIES AND EXPECTED LIFE***
- **UNIT PRICE**
- **USAGE FACTORS (PEACETIME & BATTLE)***
- **OPERATING COST**
- **MAINTENANCE RATE**
- **MAINTENANCE PHILOSOPHY***
- **MAINTENANCE LABOR COSTS**
- **AVERAGE COST OF A SPARE OR REPAIR PART**

**** USER DRIVEN***

HQ2

LIFE CYCLE COST DRIVERS

A CASE STUDY IN 1984 DOLLARS

AN ELECTRONIC LRU DEVELOPMENT (INTERFACE ADAPTER UNIT)

(CONTINUED ON NEXT SLIDE ......)

DEVELOPMENT COST

REAL, CONTRACTUALLY BINDING MONEYS

DESIGN COST	$184,008	32%
TEST COST	68,482	12
DATA COST	153,659	27
PROTOTYPE COST	143,276	25
OTHER COSTS	22,469	4
TOTAL	571,894	100

ACQUISITION COST

ALMOST REAL, TO BE REQUOTED MONEYS

SYSTEMS COST	$31,979,850	92.0%
SUPPORT EQUIP•	100,000	0.3
BASE SPARES•	2,644,950	7.6
DEPOT SPARES•	57,790	0.2
TOTAL	34,782,590	100

• INITIAL OUTFITTING: 550 BASES, 12 DEPOTS

HC2

IDA

LIFE CYCLE COST DRIVERS

A CASE STUDY IN 1984 DOLLARS

AN ELECTRONIC LRU DEVELOPMENT (INTERFACE ADAPTER UNIT)

SUPPORT COSTS

FUZZY, BLUE SKY ESTIMATES WITH MANY VARIABLES

OPERATING COST	N/A	0.0%
BASE MAINT. LABOR	$7,904,719	44.4
BASE MAINT. MATERIAL	1,312,755	7.4
DEPOT MAINT. LABOR	4,195,221	23.5
DEPOT MAINT. MATERIAL	1,009,923	5.7
TRANSPORTATION	1,227,057	6.9
CONDEMNATION SPARES	139,360	0.8
INVENTORY MGMT	2,033.507	11.4
TOTAL	17,822,542	100.0

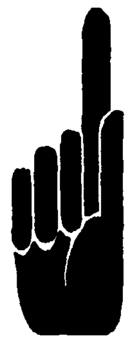
SUPPORT COST ESTIMATES ARE USED PRIMARILY FOR ASSESSING ALTERNATIVE DESIGN CONCEPTS' AND MAINTENANCE PHILOSOPHY'S RELATIVE EFFECTS

HG2

DESIGN LEVERAGE

DESIGN ENGINEERING	$184,008	
PERCENT OF DEVELOPMENT COST		32.0
PERCENT OF PRODUCTION COST		0.6
PERCENT OF SUPPORT COST		1.0
PERCENT OF LIFE CYCLE COST		0.4

(LCC = $53,177,027)

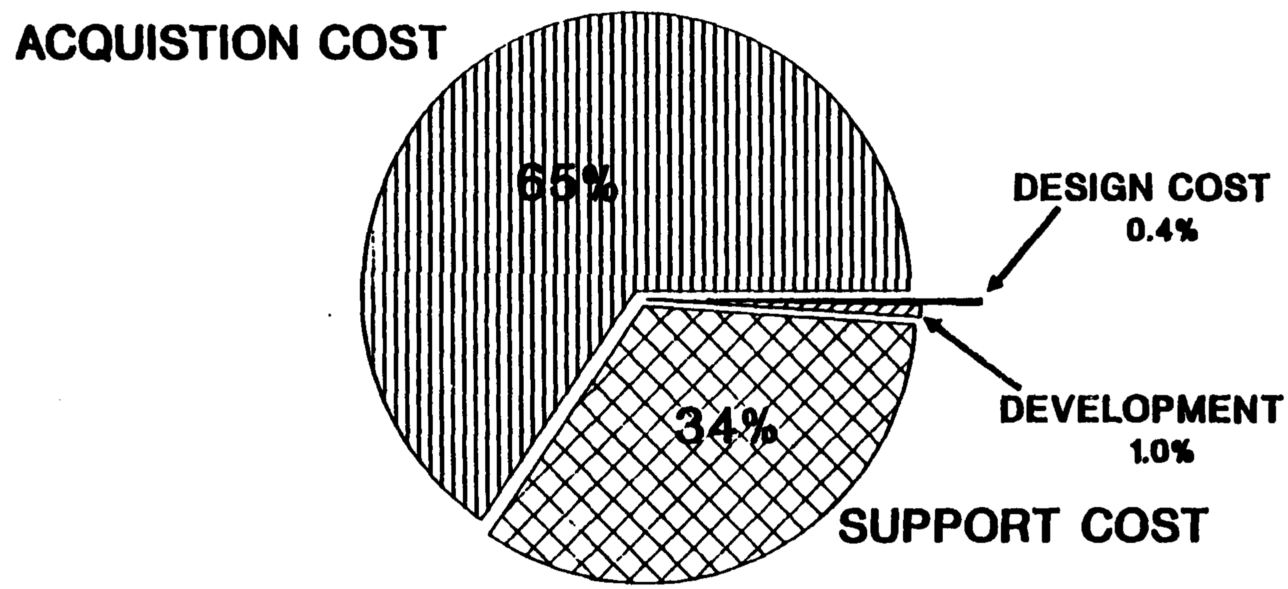


QUESTION:

HOW MUCH INFLUENCE CAN AN INSIGNIFICANT PORTION OF LCC HAVE ON LCC?

HG2

LIFE CYCLE COST OVERVIEW



HO2

IDA

SUPPORT COST SENSITIVITY

HOLDING DEVELOPMENT AND SYSTEM ACQUISITION COST CONSTANT WHILE VARYING ASSUMED HIGH LEVERAGE DRIVERS:

1. DECREASING MAINTENANCE RATE (MTBM) BY APPROX 57%
   (MTBF held constant)

   RESULTED IN $4,604,783 (25.8%) SUPPORT COST SAVINGS
   33,023 (57.1%) INITIAL DEPOT SPARES SAVINGS
   LEVERAGE = 45% MAINLY DEPOT COSTS AND BASE MT'L COSTS

2. DECREASE IN DEPOT LABOR TIME AND MAT'L COST BY 40%

   RESULTED IN $2,082,058 (11.7%) SUPPORT COST SAVINGS
   LEVERAGE = 29% DEPOT COSTS ONLY

QUESTION:

THESE RESULTS ARE ATTAINABLE WITH MORE ACCURATE ANALYSES, BETTER MAINTENANCE PROCEDURES, HIGHER MANUFACTURING QUALITY, ETC. WHAT WOULD BE POSSIBLE IF DESIGN COSTS AND PARTS QUALITY WERE ALLOWED TO INCREASE?

WHEN MUST THIS BE DECIDED?

HQ2

SUPPORTABILITY METRICS

IDA

SUPPORTABILITY CONSISTS OF:

PRIME EQUIPMENT DESIGN ATTRIBUTES

SUPPORT SYSTEM/RESOURCES ATTRIBUTES

FOR THE PRIME EQUIPMENT	*FOR THE SUPPORT SYSTEM*
RELIABILITY ANALYSES	MANPOWER REQUIREMENTS ANALYSES
SNEAK CIRCUIT ANALYSES	SKILL LEVELS
VARIOUS STRESS ANALYSES	TRAINING REQUIREMENTS
FAILURE MODES AND EFFECTS ANALYSES	QUANTITY
CIRCUIT TOLERANCE ANALYSES	SUPPORT EQUIPMENT RECOMMENDATIONS
BUILT-IN-TEST ANALYSES	CALIBRATION REQUIREMENTS
TESTABILITY ANALYSES	TOOLS REQUIREMENTS
MAINTENANCE ACTION ANALYSES	TECH DATA REQUIREMENTS
MAINTAINABILITY ANALYSES	TRANSPORTATION
MAINTENANCE ACCESS ANALYSES	HANDLING
HUMAN FACTORS ANALYSES	STOCKING
SUPPORT EQUIPMENT COMPATIBILITY ANALYSES	FACILITIES
AVAILABILITY ANALYSES	MAINTENANCE LEVEL
LIFE CYCLE COST ANALYSES	SPARES RECOMMENDATIONS
LEVEL OF REPAIR ANALYSES	PIPELINE REQUIREMENTS
ETC.	REPROCUREMENT RECOMMENDATIONS
	ETC.

THERE IS NO SINGLE MEASURE, ANY MORE THAN FOR PERFORMANCE BUT INDIVIDUAL MEASURES CAN BE RANKED FOR IMPORTANCE TO A PARTICULAR APPLICATION TO THEN FORM A RELATIVE "S" FACTOR

HQ2

Appendix B

SAMPLE SPECIFICATION PARAGRAPHS FOR DEVELOPMENT SPECIFICATIONS

To ensure design engineering and management recognition and support of the utilization of Unified Life Cycle Engineering (ULCE) principles requires appropriate statements in the Statement of Work (SOW), and in some portions of the quality assurance provisions of a development specification. Requiring ULCE, however, will at best ensure that the design meets its specified requirements. Improvements in reliability and maintainability (R&M) will therefore also require some improvement in the manner in which essential design requirements are specified and incentive, or value-added, clauses should be added to the contract, the Request for Proposal (RFP), and instructions to bidders. The following are recommended sample statements for Reliability, Maintainability and Logistics (R,M&L) portions of development specifications, which, together with a properly structured SOW, will provide for use of contemporary ULCE techniques, as well as correction of some of the more dominant R&M problems. The author is cautioned to avoid specifying how the techniques are to be used and to refrain from requiring specific techniques if generic techniques will suffice.

The sample paragraphs are to be used in addition to, or replacement of the counterpart paragraphs in contemporary specification guidance documents. Paragraph numbers are only illustrative (following MIL-STD-490), since the paragraph structure will vary according to each Services' specification preparation guide, as well as the program's specific requirements.

The sample paragraphs do not constitute an entire specification. Instead they are intended to represent those portions of a typical specification that will affect on the ULCE application to the design process.

Reliability. The design of the (Contract Item) shall be such that the specified reliability requirements shall be attained at ____ percent risk to the Government, as validated in accordance with the quality assurance provisions of paragraph 4._._. Control of, and interaction with the design and manufacturing processes shall be formal, specifically tailored, and timely, as provided in the SOW, to ensure reliability by design.

(Note to authors: To force the implementation of ULCE, a rigorous allocation/prediction utilization for design interaction must be enforced. Otherwise any adequate analyses could be used and specification compliance could be based strictly on demonstration results, which reflect only a small sample of time, performance, and environmental exposure.

Therefore the link to QA provisions is emphasized here and in the SOW to ensure that the analytical techniques specified there are also used in the design process.

This section should also contain, if required, the periodic inspection cycles of an item in storage, such as a missile, if such inspection could affect reliability or readiness.

There are several techniques for specifying reliability in terms of performance criticality. If specific performance parameters can be identified, the following technique should be used).

3.2.3.1 Inherent reliability. The (Contract Item) shall have a minimum mean time between failure (MTBF) of _____hours for all (Contract Item) level performance requirements during all combinations of operational and environmental conditions specified in paragraphs 3.2.1 (Performance) and 3.2.5 (Environmental Conditions) herein. The serial MTBF under the same conditions shall not be less than ______hours. In addition, the following critical performance requirements shall have the minimum mission Reliability (R_m) and Availability (A_i) Figures of Merit (FOMs):

	REQUIREMENT	PARAGRAPH	R_m	A_i
a.				
b.				
c.				
etc.				

xxxxxxxxxxxx OR ALTERNATELY xxxxxxxxxxxx

(NOTE to authors: If specific performance parameters cannot be identified, the following technique should be used.):

3.2.3.1 Inherent reliability. The (Contract Item) shall have the following minimum mean time between failures (MTBFs) for all (Contract Item) level performance requirements during all combinations of operational and environmental conditions specified in paragraphs 3.2.1 (Performance) and 3.2.5 (Environmental Conditions) herein:

a. Mean time between critical failure ($MTBF_{crit}$): ______hours

b. Mean time between major failure ($MTBF_{maj}$): ______hours

c. Mean time between minor failure ($MTBF_{min}$): ______hours

d. Mean time between serial failure ($MTBF_{ser}$): ______hours

Where $MTBF_{crit}$, $MTBF_{maj}$, $MTBF_{min}$, and $MTBF_{ser}$ shall be as defined in paragraph 6._.

(Note to authors: The following paragraph should be included only if a value-added, incentive, or warranty provision is contained in the contract.)

3.2.3.2 Reliability improvements. Reliability analyses shall identify candidate design changes and/or parts application that have the potential to improve upon the specified reliability FOMs, as well as provide a higher degree of confidence (than specified) that actual field experience will be equal to or better than the predicted inherent reliability FOMs. For purposes of comparison a sample of ____ (Contract Items) operating for a combined period of ___ MTBFs shall be considered. The results of these analyses shall be made available to the Government in sufficient time prior to design release so as to preclude significant redesign if the Government were to approve the change(s). (If the contract contains incentives or warranties along these lines add: "as provided by the contract.") The results of the analyses shall include the effects and/or compromises on any other requirement(s) specified herein.

3.2.3.3 Built-in-test reliability.

3.2.3.4 Useful life.

3.2.3.5 Reliability design criteria.

(Note to authors: The list can be expanded to include other design criteria peculiar to the Contract Item. The preceding examples represent the most critical to attaining the required reliability.)

3.2.3.5.1 Parts selection.

3.2.3.5.2 Parts application. Parts application shall, to the maximum extent possible optimize between failure rate, part cost, next higher assembly level(s) cost, part availability, commonality, spares cost, and reprocurement. Parts application determinations shall precede actual parts selection and continue throughout the design phase to ensure maximum commonality between all applications. Optimization shall not compromise performance or reliability requirements.

3.2.3.5.3 Part derating.

3.2.3.5.4 Junction temperatures.

(Note to authors: To force the implementation of ULCE, a rigorous allocation/prediction utilization for design interaction must be enforced. Otherwise any kind of adequate analyses could be used, and specification compliance could be based strictly on

demonstration results, which reflect only a small sample of problems and maintenance actions. Therefore the link to QA provisions is emphasized here and in the SOW to ensure that the analytical techniques specified there are also used in the design process.)

3.2.4 Maintainability. The design of the (Contract Item) shall be such that the specified maintainability requirements shall be attained at ____ percent risk to the Government, as validated in accordance with the quality assurance provisions of paragraph 4._._. Control of, and interaction with the design and manufacturing processes shall be formal, specifically tailored, and timely, as provided in the SOW, to ensure maintainability by design.

3.2.4.1 Inherent maintainability.

3.2.4.1.1 Organizational-level maintenance.

3.2.4.1.1.1 Corrective maintenance time.

3.2.4.1.1.2 Fault detection and isolation.

3.2.4.1.1.3 Fault correction.

3.2.4.1.1.4 Verification of fault correction.

(Note to authors: The contents of this paragraph are essential to an integrated diagnostics concept. If an embedded maintenance expert system technique is to be used, appropriate statements should be added.)

3.2.4.1.1.5 Manual intervention tests. Manual intervention tests shall, in conjunction with the (Contract Item's) BIT, provide for a complete functional check, fault detection, and fault isolation of the (Contract Item), including its interfaces to the next higher system level. The balance between BIT and external support equipment for this purpose shall be optimized prior to the start of equipment design, to a degree sufficient to preclude subsequent iterative optimization from effecting significant redesign. Integrated diagnostics techniques employed for this optimization shall include technical, maintenance scenario, as well as life cycle cost (LCC) considerations. As a minimum, the (Contract Item) shall be designed to permit manual intervention tests for operability from the front of the unit without the need to disconnect, shut off power, or change any of the programming contained in the unit. *(Note to authors: Depending on the maintenance philosophy, it may be desirable to change programming, etc.)*

3.2.4.1.1.6. Preventive maintenance time.

3.2.4.1.1.7 Calibration and adjustment.

3.2.4.1.2 Intermediate-level maintenance.

3.2.4.1.3 Depot-level maintenance.

(Note to authors: By combining built-in test (BIT) with automatic test equipment (ATE) capabilities, a higher percentage fault isolation can be attained than with either used alone. Care should be taken so that automatic fault detection/isolation is not specified in too great detail because the UUT, test routines, and ATE will become very expensive. A rough integrated diagnostics optimization should be made by the Government considering shop loading, skills, etc., to determine the minimum level of automation versus manual intervention or guided probing techniques. Alternately the prospective bidder could be asked to do this as part of his pre-proposal input, showing cost benefits to the Government. However, the final specification for the bidding must contain firm, minimum requirements.)

3.2.4.1.3.1 Fault detection and isolation. Detection and isolation of LRU and SRU faults, as well as SRU interface faults, shall be accomplished by the BIT and ATE test routines to the following ambiguity levels. The remaining faults shall be detected and isolated with no ambiguity utilizing manual intervention tests.

a. LRU fault detection. ____ percent of all possible LRU faults, including input/output faults shall be correctly detected and identified using BIT and ATE.

b. LRU fault isolation. LRU faults shall be isolated to the SRU level, hard-wired component and chassis wiring with the following ambiguity levels using BIT and ATE:

   (1) To a single SRU ___ percent of the time

   (2) To two SRUs ___ percent of the time

   (3) To no more than three SRUs 100 percent of the time

   (4) To a single hard-wired component or chassis wire ___ percent of the time.

c. SRU fault detection. ____ percent of all possible SRU faults, including input/output faults shall be correctly detected and identified using ATE.

d. <u>SRU fault isolation</u>. Faults within repairable SRUs shall be isolated to the component or sub-SRU level with the following ambiguity levels using ATE:

(1) To a single component or sub-SRU ___ percent of the time

(2) To a group of 10 percent of the total components or sub-SRUs ___ percent of the time

(3) To a single functional stage or functional group of sub-SRUs ___ percent of the time

(4) For purposes of fault isolation, component failures shall be as defined in RADC-TR-79-327.

e. <u>Sub-SRU fault isolation</u>. Same as SRU fault isolation.

3.2.4.1.3.3 Fault correction.

3.2.4.1.3.4 Verification of fault correction.

3.2.4.1.3.5 Manual intervention tests. Manual intervention tests shall, in conjunction with the automated tests, provide for a complete functional check, fault detection, and fault isolation of the UUT, including its interfaces to the next higher level of assembly. Manual intervention procedures and technician guidance shall be contained within the test program and shall be available to the technician at the proper point in the diagnosis and whenever called up by the technician. The balance between test UUT features, test routines, and ATE interface devices for this purpose shall be optimized prior to the start of equipment design, to a degree sufficient to preclude subsequent iterative optimization from effecting significant redesign. Integrated diagnostics techniques employed for this optimization shall include technical, maintenance scenario, as well as LCC considerations. As a minimum, the UUTs shall be designed to permit manual intervention tests using test points contained on the UUT. Circuit probing, which would pierce protective coatings or otherwise damage the UUT, is not permitted.

3.2.4.1.3.6. Preventive maintenance time.

3.2.4.1.1.7 Calibration and adjustment.

(Note to authors: The following paragraph should be included only if a value-added, incentive, or warranty provision is contained in the contract.)

3.2.4.2 Maintainability improvements. Maintainability analyses shall identify candidate design changes that have the potential to improve the specified maintainability FOMs, as well as provide a higher degree of confidence (than specified) that

maintainability FOMs calculated from actual field maintenance experience will be equal to or better than the predicted inherent maintainability FOMs. The results of these analyses shall be made available to the Government in sufficient time prior to design release so as to preclude significant redesign if the Government were to approve the change(s). (If the contract contains incentives or warranties along these lines add: "as provided by the contract.") The results of the analyses shall include the effects and/or compromises on any other requirement(s) specified herein.

(Note to authors: A major problem with BIT performance versus expected performance stems from ambiguous requirements. FOMs are usually expressed in terms of a percentage of failures with no clarification or ranking of importance; therefore, unimportant high-failure rate circuits could have better detection and isolation than important low-failure rate circuits. False alarms are also usually specified in terms of a percentage of something--which is usually misunderstood. A better way of expressing false alarms is in terms of quantity per operating time. The following serve as examples of a more definitive technique.)

3.2.4.3 Built-in-test (BIT). The (Contract Item) shall contain BIT features capable of conducting self-test, manual intervention tests, and fault detection and fault isolation, as follows:

3.2.4.3.1 Continuous automatic self-test. The (Contract Item) shall be designed to evaluate its overall performance automatically at a rate of not less than one complete cycle every ___second(s). Steady state functions such as power supplies, phase locked loops, cooling, and protective devices shall be monitored continuously. The self-test shall rely entirely on the BIT features contained in the (Contract Item). No additional equipment, external controls, or support equipment shall be required to perform self-test. The self-test shall not interfere with any of the operational performance characteristics and capabilities of the (Contract Item). The self-test shall provide the following organizational-level, on-line fault detection capabilities:

a. Detect ___ percent of all functional performance degradations that would constitute a critical (Contract Item) failure, with exception of (Contract Item) interfaces to the next higher system level.

b. Detect ___ percent of all those functional performance degradations that would constitute a major (Contract Item) failure.

c. Detect 100 percent of the performance degradations listed in Table 3-1 and generate the attendant outputs.

d. Status of BIT fault detection monitoring circuits shall be reported on the (bus, connector, etc.) when strobed by an external initiating command in accordance with Table 3-1.

e. The false alarm rate (declaring a failure where none exists) shall be less than one false alarm within any consecutive ___hours of operation.

f. Fault detection time shall be in consonance with the specified M_{ct} and M_{maxct}.

Table 3-1. Performance degradations

PERFORMANCE REQUIREMENT	REF.PARA.	REQUIRED BIT OUTPUT
1.		
2.		
etc.		

3.2.4.3.2 Fault isolation. The (Contract Item) shall be designed to fault isolate to the malfunctioning LRU when initiated by a control signal to the following FOMs:

a. BIT shall unambiguously isolate ___ percent of all reported critical failures or unsafe conditions to a single LRU when initiated by the control signal.

b. BIT shall unambiguously isolate ___ percent of all reported major failures to a single LRU when initiated by the control signal.

c. BIT shall unambiguously isolate ___ percent of all reported major failures to the failed performance function automatically and report to the (onboard computer) via _________, such that workaround procedures can be effected.

d. LRU BIT shall isolate a fault to an SRU in conjunction with approved support equipment to the following ambiguities:

(1) To a single SRU ___ percent of the time

(2) To two SRUs ____ percent of the time

(3) To no more than three SRUs 100 percent of the time.

3.2.4.3.3 BIT interface definition. *(Note to authors: State the required interface signals, connectors, timing, etc. The testability requirements guidance in RADC-TR-79-327 and MIL-STD-2165 adequately describe the requirements to be specified under "Testability" and "Test Programs." However, the following considerations should be*

added to improve the assistance that BIT can offer for LRU testing, as well as to ensure properly designed, cost effective testability programs.)

3.2.4.4 Testability. BIT and automated checkout and fault detection shall be possible by use of only the normal input/output connector(s) of the UUT. Test points contained on a test connector or in other locations on the UUT shall not be required for this purpose.

3.2.4.4.x Test programs. Test programs shall comply with the requirements of MIL-STD-2076 and MIL-STD-2077, and be automatically prepared by the computerized testability analyses of paragraph 4._._._ to the maximum extent possible. As a minimum, the test program shall include all input signal patterns, fault signatures, and suspect components against these signatures as identified by the analysis. If the analysis program is not capable of generating the test program, it shall be possible to transport this information entirely to the test program generator without manual transcription or keyboarding.

3.2.4.5 Other maintainability design features.

(Note to authors: The lists of design features found in MIL-STD-470, MIL-STD-2076, MIL-STD-2084, MIL-STD-2165, RADC-TR-79-327, RADC-TR-83-257, and many related texts are adequate for this paragraph. One need only add features peculiar to a two-level maintenance concept, if this were required)

3.5 LOGISTICS.

(Note to authors: The normal maintenance and maintenance analyses provisions invoking MIL-STD-1388A are adequate for this section. The requirement for automated technical (design) information (ATI), transfer for use in planning, LSAR preparation, automated technical orders (ATOS), maintenance instruction preparation, etc., must be added.)

3.5.3 Maintenance.

3.5.4 Supply.

4.0 QUALITY ASSURANCE PROVISIONS.

(Note to authors: The usual quality assurance provisions regarding analyses, demonstrations, demonstration failures, inspections, etc., are adequate for ULCE. What is required is the definition of analytical techniques that are automated and performed in time

to influence the design and control its release to manufacturing. Analyzing and predicting design risk is also important in the apportionment/analyses/design feedback process.)

4.X.X Reliability.

4.X.X.1 Reliability risk analyses. Reliability risk analyses shall be conducted in accordance with MIL-STD-499 and the guidance of the *System Engineering Management Guide*, Defense Systems Management College. The accuracy and timely design implementation of the analytical techniques employed to assess reliability FOMs shall be a major risk factor. Computerized techniques that comply with the requirements of MIL-STD-785 and MIL-HDBK-217 shall be considered a low design risk. If, in addition, these programs were to interface/interact directly with the design process, so as to preclude design release of an item that has not been subjected to analyses and approval, that shall be considered the least risk possible.

4.X.X.2 Reliability analyses. Reliability FOMs shall be analyzed throughout the design process to test compliance with specified requirements as apportioned to the item being designed. Analyses shall be started at the conceptual design phase with satisfactory results being requisite to making the transition to the next phase of design, development, or manufacture. No design shall be released without having first been analyzed to comply with specified and/or allocated requirements. Unless unavailable as contemporary hardware/software, all reliability analyses shall be performed with computer techniques in a sufficiently timely manner to control design release. (The contractor shall identify the techniques to be used in his proposal.) As a minimum, the following analyses shall be performed.

4.X.X.2.1 Numerical allocations. The allocated reliability FOMs shall be used to ascertain compliance with the reliability specifications of each item analyzed. In no event shall the sum of the allocations, including rounding errors, exceed the specified values of the (Contract Item).

4.X.X.2.2 Electrical stress analysis. Computer techniques shall be employed to analyze the candidate circuit under all operating conditions. Individual component stresses shall be identified during that analysis and sorted into high, median, and low stresses for each component. The information shall be retained for the reliability prediction.

4.X.X.2.3 Thermal stress analysis and survey. Computer techniques shall be employed to calculate the wattage dissipation of each component as a result of the electrical stress analysis. High, median, and low dissipation shall be recorded. A thermal survey shall then be made of the proposed mechanical layout using the wattages calculated from the thermal stress analysis, knowledge of ambient temperatures, cooling provisions, and heat radiated from adjacent circuit boards or assemblies. The result of the survey shall be used to calculate component temperatures, including junction temperatures of semiconductor devices. The results of the analyses and surveys shall be stored for use in the reliability predictions.

4.X.X.2.4 Mechanical stress analysis. Computer techniques shall be employed to analyze mechanical stress under all operating and storage conditions. The technique shall be capable of predicting amplifications, dampening, and resonances. The depth of the analysis shall be sufficient for use in the reliability predictions beginning with the component. The results shall be stored for that purpose.

4.X.X.2.5 Reliability predictions. Reliability predictions shall be performed for all levels of assembly using as inputs the results of the stress analyses and the actual parts and parts quality from the design information. Unless it can be shown that mission profile analyses would be more representative of field reliability, the worse combination of electrical, thermal, and mechanical stresses shall be employed to predict reliability. The reliability predictions shall be in accordance with MIL-HDBK-217 and shall analyze each component and piece part of the (Contract Item). The results of the predictions shall be compared to the numerical allocations for each item analyzed. Items failing to meet the numerical allocation shall be rejected, unless a re-allocation can be accomplished using "excess" MTBF from some other item and redistributing that excess. Design approval can only be granted if the prediction meets or betters the numerical allocation. Design approval, however, is limited to release of drawings for manufacture of prototypes and/or pilot production runs. Ultimate design approval requires both a prediction whose result is compliant with the numerical allocations and satisfactory demonstrations results.

4.X.X.X.6 Worst-case tolerance analysis. Electrical tolerance buildup shall be modeled using computer techniques to ascertain whether tolerance extremes would render a circuit inoperable. Similarly, mechanical items shall be analyzed to ascertain whether mechanical extremes would cause excess wear or inability to perform. Where

tolerance buildups indicate performance problems, the design shall be rejected and the problem brought to the attention of the design engineer. Tolerance analysis shall also consider the effects of electrical, thermal, and mechanical stress. The results of the analysis shall be used for the failure modes and affects analysis.

4.X.X.2.7 Sneak circuit analysis. Sneak circuit analysis shall be conducted on all analog circuits, control circuits, and circuits involving relays and switches. Unless it can be demonstrated that digital circuit design had employed an approved design aiding program using Boolean algebra or similar technique to check performance, a sneak circuit analysis shall be performed by reliability as prerequisite to a testability analysis. The result of these analyses shall be used to assess the acceptability of the design. There shall be no sneak circuits nor any semiconductor device that does not have an effect on the circuit transfer characteristics when either stuck in a high or stuck in a low position. Any problems shall be cause for rejection and shall be identified for corrective action. The results of the sneak circuit analysis shall be stored together with the circuit information for the testability analysis.

4.X.X.2.8 Failure modes-and-effects analyses. A computerized failure modes-and-effects analysis shall be performed employing techniques that comply with MIL-STD-1629. A top-down failure modes-and-effects analysis shall be performed at the system level for use in the BIT design. The results of the failure modes-and-effects analyses shall be stored for use by maintainability.

4.X.Y Maintainability

4.X.Y.1 Maintainability risk analyses. Maintainability risk analyses shall be conducted in accordance with MIL-STD-499 and the guidance of the *System Engineering Management Guide*, Defense Systems Management College. The accuracy of, and timely design implementation of the analyses techniques employed to assess maintainability FOMs, shall be a major risk factor. Computerized techniques that comply with the requirements of MIL-STD-470, MIL-STD-2165, RADC-TR-79-327, RADC-TR-83-257, and MIL-HDBK-472 shall be considered of low design risk. If, in addition, these programs were to interface/interact directly with the design process, so as to preclude design release of an item that has not been subjected to analyses and approval, that shall be considered the least risk possible.

4.X.Y.2 Maintainability analyses. Maintainability FOMs shall be analyzed throughout the design process to test compliance with specified requirements as apportioned to the item being designed. Analyses shall be started at the conceptual design phase with satisfactory results being requisite to transitioning to the next phase of design, development, or manufacture. No design shall be released without having first been analyzed to comply with specified and/or allocated requirements. Unless unavailable as contemporary hardware/software, all maintainability analyses shall be performed with computer techniques in a sufficiently timely manner to control design release. (The contractor shall identify the techniques to be used in his proposal.) As a minimum, the following analyses shall be performed.

4.X.Y.2.1 Numerical allocations. The allocated maintainability FOMs shall be used to ascertain compliance with the maintainability specifications of each item analyzed. In no event shall the sum of the allocations, including rounding errors, exceed the specified values of the (Contract Item).

4.X.Y.2.2 Corrective maintenance analysis. Corrective maintenance analysis shall be performed in accordance with MIL-HDBK-472, Procedure II, Part B. The analysis shall be performed on every repairable item of the (Contract Item). Inputs to the analysis shall be obtained from the reliability predictions, sneak circuit analysis, built-in-test, and testability analyses, and for mechanical construction of the item being analyzed. The steps for fault isolation, removal and replacement, adjustment and checkout used for the analysis shall be captured for input to the LSAR and technical manual preparation. The results of the corrective maintenance analysis shall be compared with the numerical allocations. Unless allocations can be redistributed, failure to meet the allocations shall be cause for rejection of the item being analyzed. Compliance with the numerical allocations is requisite to design approval for purposes of drawing release for manufacturing of prototypes and/or pilot productions equipment. Ultimate design approval requires both an analysis whose result is compliant with the numerical allocations and satisfactory demonstration results.

4.X.Y.2.3 Preventive maintenance analysis. Preventive maintenance analysis shall be prepared in accordance with MIL-HDBK-472. Inputs to the preventive maintenance analysis shall be obtained from the reliability predictions and reliability analyses. If a reliability-centered maintenance analysis was performed, the results shall also be input to the preventive maintenance analysis. Compliance with the numerical

allocations shall be requisite to design approval. Output of the preventive maintenance analysis shall be captured for use by the LSAR and technical manual preparation.

4.X.Y.2.4 Accessibility analysis. An accessibility analysis shall be performed employing anthropometric techniques for all items where such access cannot be readily envisioned. Access and manipulation of tools, lifting, removing, and replacing shall be in accordance with the specified human factors requirements, maintenance philosophy, and maintenance environment. Compliance with these requirements as analyzed shall be requisite to design for approval for purposes of drawing release for manufacturing of prototypes and/or pilot productions equipment. Ultimate design approval requires both an analysis whose result is compliant with the numerical allocations and satisfactory demonstration results.

4.X.Y.2.5 Manpower requirements analysis. The result of the corrective and preventive maintainability analysis shall be input to a manpower requirements analysis. The results of this analysis shall be compared to the specified manpower requirements. Compliance with the specified manpower requirements is requisite to design approval for the purpose of drawing release to manufacture of prototypes and pilot production runs. Final approval is dependent on the Governments' acceptance of the analysis. Output of the analysis shall be stored for input to the LSAR.

4.X.Y.2.6 BIT analysis. A combination of computer and manual techniques shall be employed to analyze the built-in-test capabilities. The analysis shall be based on MIL-HDBK-472 and the *Built-In-Test Design Guide* NAVMAT-P-9405. Input to the BIT analysis shall be obtained from the top-down FMECA of the (Contract Item). Compliance with the specified requirements shall be requisite to approval of the (Contract Item). However, if portions of the BIT facilities were allocated to reside in assemblies and subassemblies, they shall require validation that the allocated performance or circuits, or test facilities are contained in that item. Final approval of the (Contract Item) is predicated on acceptance of the demonstration results.

4.X.Y.2.7 Testability analysis. A testability analysis shall be performed in accordance with MIL-STD-2165. The testability analysis shall employ computer techniques and derive its input from the schematics and transfer characteristics of the circuit being analyzed. The result of the analysis shall predict the testability indices. Compliance with the allocated testability indices (i.e., fault detection and fault isolation) is requisite to design approval for prototype production and/or pilot production. Results of the testability

analysis shall be stored for input to the LSAR, test program, and test program set preparation.

6.0 NOTES.

6._ DEFINITIONS.

6._.1 Failure Definitions. Failures are classified in accordance with the following definitions:

a. Critical Failure. A critical failure is defined as any failure that causes all performance capability to be lost (or, alternately, those performance parameters specified as critical).

b. Major Failure. A major failure is defined as any failure that reduces performance of the (Contract Item) such that some, but not all capability is lost, and the mission may be completed. In addition, a major failure is any failure that:

   (1) loses service to an input or output connection.

   (2) prevents BIT from detecting major failures in on-line hardware or firmware.

   (3) causes BIT to continuously identify a major failure in on-line hardware when such failure does not exist.

   (4) prevents BIT from isolating/localizing, to the LRU when such failure does exist.

   (5) causes the BIT false alarm rate to exceed that specified.

c. Minor Failure. A minor failure is defined as any failure that impairs the (Contract Item), but does not cause the (Contract Item) to reconfigure. There is no degradation in performance. In addition, a minor failure is any failure that impairs BIT performance (creates false alarms), but permits BIT, when reset/recycled, to isolate/localize to the LRU.

6._.X Inherent maintainability. Inherent maintainability consists of those characteristics of design that would result in the ability to perform all maintenance actions within their predicted FOMs, utilizing the support resources, manpower, skills, and facilities commensurate with the maintenance concept considered in the prediction.

6._.Y Inherent reliability. Inherent reliability consists of those characteristics of design that would result in attaining the predicted MTBF if an infinite, or sufficiently

large, number of equipments were operated over an infinite, or sufficiently large, amount of time, under the operating conditions upon which the analysis was based.

Appendix C

SAMPLE STATEMENT OF WORK PARAGRAPHS FOR TYPE II (DEMONSTRATION AND VALIDATION) PHASE

The following are recommended sample statements for appropriate portions of development type Statements of Work (SOWs), which together with a properly structured specification will provide for use of contemporary Unified Life Cycle Engineering (ULCE) techniques; however, the author must take care to avoid specifying how they are to be used. The author is cautioned to refrain from requiring specific techniques if generic techniques will suffice. Nor should analytic techniques that are either not available or acceptable as computerized techniques be required for a particular application.

The sample paragraphs are to be used in addition to, or replacement of, the counterpart paragraphs in contemporary SOW guidance documents. Paragraph numbers are only illustrative (following MIL-HDBK-245B), since the paragraph structure will vary according to each Services' SOW preparation guide, as well as the program's Work Breakdown Structure.

The sample paragraphs do not constitute an entire SOW. Instead they are intended to represent those portions of a typical SOW that affect the ULCE application to the design process.

2. SCOPE

(Note to author: as part of paragraph 2. or 3., add the following paragraph:)

2.x._. Design and producibility technology. Design and development of the (Contract Item) shall employ Unified Life Cycle Engineering (ULCE) principles consisting of integrated/interactive Computer-Aided Engineering (CAE), Computer-Aided Drafting (CAD), Computer-Aided Manufacturing (CAM), and Computer-Aided Logistic Support (CALS) to the maximum extent possible, employing currently available, computer techniques that have been approved (for the application, i.e., MIL-STD-217 predictions).

(Note to author: A list of approved techniques should be contained in the Instruction to Offerers.)

2.x._._. Computer-aided logistic support. As a minimum, timely, interactive design guidance, analyses, and feedback shall be used during the design and development phases of the (Contract Item) to achieve design attributes that will enhance the reliability, maintainability, testability, and supportability of the equipment. Reliability, maintainability, and logistics issues in design, particularly CAE, are the most essential

portion of ULCE. Techniques shall be employed to provide a design that is tailored and optimized not only from the standpoint of readiness and availability but also from supportability. The products resulting from the computerized techniques shall also provide the information necessary for logistic support planning, the preparation of technical manuals, the defining and optimization of spares procurement and placement, the technical requirements for test and other support equipment, as well as the test procedures, the built-in-test routines, and all the data products necessary for the LSAR.

In addition, traceable feedback shall be provided during active design to identify design enhancements that may improve R,M&S well beyond what is specified and in a manner that will not compromise cost, schedule, or performance of the equipment. The analytical techniques should be employed and carefully timed to discover design problems, input/output mismatches, manufacturing, and test problems, etc. The techniques should also provide the most authoritative and useful products for the logistic support planning and resources acquisition.

The process must take place during the active design phase, prior to the release of drawings or design information for the manufacture of the equipment, and shall be controlled by the project manager and quality assurance functions.

3.1 QUALITY PROGRAM. The contractor shall plan and conduct a quality program in accordance with MIL-Q-9858. The program shall contain provisions for formal analyses and demonstrations to validate that all specified requirements have been met, in accordance with the provisions of Section 4 of the development specification. Provisions for design review and control procedures, design audit trails, and utilization of digitized design information for planning and preparation of support resources shall also be included.

3.1.1 Quality program implementation. The contractor shall plan and conduct a program that will ensure that proper controls are placed on the design, as well as the manufacturing processes, to ensure that the design, reliability, maintainability, and testability risks do not exceed those specified. The quality program shall also ensure that formal design controls are implemented to provide that reliability, maintainability, and testability attributes are obtained by tangible design features, rather than mere mathematical manipulations. The program shall ensure that an approved set of contemporary computer techniques are employed to interact with the design process such that performance, reliability, maintainability, testability, weight, cost, etc., are all considered during the

design process by the design engineer. The quality program shall establish formal internal design reviews to ensure that translating of all design, reliability, and maintainability requirements into the design features; analyzing the proposed design; and active feedback recommendations for improvement and optimization are established and enforced. In addition, the quality assurance program shall provide that no drawings are released for production without the approval of manufacturing engineering, reliability, maintainability, and logistics.

3.1.2 Design audit trail. The contractor shall establish a procedure to capture in digital format, disseminate, and formally control, technically accurate engineering information pertaining to design and performance characteristics that are essential as a design-related data base for all other design and LSA tasks. These data shall be prepared and controlled in a timely and orderly manner concurrent with the design process, to serve as the design audit trail for support resource planning, design trade-off study inputs, and LSAR preparation. As a minimum, they will define interconnections, interfaces, power, signals, tolerance, schedule, cost, and other budgets, as well as signal names.

3.1.3 Design review. The contractor shall provide for official design reviews during the design process and control of all released design information such that the appropriate support disciplines also participate in the approval cycle in a timely and controlled manner. A formal closed loop means of identifying problems that need attention or correction shall be established. All users of the design information shall have the opportunity to offer solutions to problems that may be discovered or suggestions for design improvement. This review and approval shall serve as the formal control of design by Program Management and LSA Management.

3.1.3.1 Task description. The contractor's existing plan and procedures for design review and approval may be used to the fullest extent possible. The plan shall include the design review requirement of the LSA Plan, to ensure compliance with the ILS specification. The design review procedures thus established shall define the accept/reject criteria pertaining to support-related design requirements. Guidance for these shall be developed from:

a. The specified performance and support-related requirements

b. The translation of reliability, maintainability, manpower, and support requirements to design guides/constraints

c. Adherence to qualitative/quantitative reliability, maintainability, and allocations and analytical techniques and accuracy requirements.

3.1.3.2 Task documentation. A method of documenting the design review shall be established. The documentation shall be non-deliverable, but shall be available for review by the Government. The documentation shall be indexed with a rational numbering scheme (i.e., WBS numbers). The documentation shall contain the approval signatures' affiliation, i.e., design/support/engineering/management and date of final approval. Recommendations for improvement, alternate design, or causes for rejection shall be briefly described on continuation sheets. Space shall be provided to document the disposition of each comment. These notations shall provide an audit trail for design evolution.

3.1.3.3 Procedures. All design review procedures shall be established immediately upon the start of the development program. The design review procedures shall establish the types of documentation to be reviewed by each of the various reviewing activities together with their degree of authority for review/acceptance/rejection/final authority. A list of the types of documentation subject to formal review by the support disciplines shall be submitted to the Government as part of the LSA Plan, the ILS Plan, or the Quality Control Plan as deemed most appropriate by the contractor, in consonance with other contractual requirements. Each plan, however, shall contain reference to this list as well as to the design review procedures. Typical documents, or counterpart digitized design information, subject to formal review are

a. Functional block diagrams

b. Assembly drawings

c. Repairable subassembly drawings

d. Installation drawings

e. Envelope drawings

f. Schematics

g. Wiring diagrams

h. Parts control drawings

i. Specification control drawings

j. Source control drawings

k. Test/Performance specification

l. Acceptance test procedure

m. Qualification test procedure

n. Similar subtier contractor specifications that have a major effect on overall design.

3.2 DESIGN, DEVELOPMENT, AND FABRICATION

3.2.1 Design and development.

3.2.1._. System synthesis. System synthesis shall be performed in accordance with MIL-STD-499 and the guidance of the *System Engineering Management Guide*, Defense Systems Management College. System Engineering shall perform system synthesis through system/segment specification and Interface Control Document (ICD) preparation; development of schematic block diagrams and system simulations; and preparation of equipment lists, weight lists, command telemetry lists, and other products of their integration function.

(Note to author: Add the following paragraph as part of the system synthesis requirements)

The performance, configuration, and arrangement of the (Contract Item) and its elements, and the technique for their test, support, and operation shall be portrayed in a form such as a set of schematic diagrams, physical and mathematical models, computer simulations, layouts, detailed drawings, and/or similar engineering graphics. These portrayals shall illustrate intra- and inter-system and item interfaces, permit traceability between the elements at various levels of system detail, and provide means for complete and comprehensive change control. This portrayal shall be the basic source of computerized data for developing, updating, and completing the following:

a. The system, configuration item, and critical item specifications

b. Interface control documentation

c. Consolidated facility requirements

d. Content of procedural handbooks, placards, and similar forms of instructional data

e. Task loading of personnel

f. Operational computer programs

g. Specification trees

h. Dependent elements of work breakdown structures.

3.2.2._. System requirements allocations. The contractor shall conduct a functional analysis based on the specified functional, reliability, and maintainability requirements for the (Contract Item) and allocate these requirements to the subassembly level. The contractor shall identify allocated requirements in sufficient detail to show traceability from the overall (Contract Item) level requirements to the critical item specifications and computer program development specifications, if any. The contractor shall prepare a specification tree for the configuration items and computer programs to be developed, if any. The contractor shall consider the impact of eventual improvements (Pre-Planned Product Improvements) including Reliability and Maintainability.

(Note to author: If incentives are involved, add "as provided in the improvement incentives clause of the contract.")

3.2.2._._. The information required shall be planned for, collected, and documented in computer automated contractor format (i.e., word processor) to serve as an instrument of communicating technical information between design engineers for purposes of maintenance planning, analyses, handbook and software inputs, trade-offs etc. The formatting of this information shall be planned to avoid all duplication of efforts (translations, transcriptions, etc.) for it to serve both purposes. The information shall include the following items, modified as appropriate for the item described:

a. A concise narrative description of the operation and function of the item. Its role in the next higher assembly (if any) and, if controlled by external commands, how it operates in the different modes. This discussion should be very similar to what would be normally found in a technical proposal, but much briefer.

b. Supporting documentation (or reference to the computer file containing the information), such as schematics, block diagrams, signal flow diagrams, timing diagrams, etc., as appropriate and necessary to fully describe the item, what it does, and how it does it.

c. A concise description of Built-In-Test (BIT) allocations, features, functions, and capabilities or participation in the BIT routine, if any. If the item plays a passive role during BIT, information that would ensure that the required level of checkout can be accomplished using BIT shall be provided.

d. A description of adjustments and under what circumstances they must be made. The test facilities with which to effect the adjustment shall be included. In view of the fact that adjustments usually are undesirable, a technical

rationale as to the need for the adjustment, together with the alternates tried and the reason for not using them shall be provided.

e. A summary of the design analyses prepared to date.

f. A substantiation or reference to supporting documentation for the production unit cost, cost as a spare, and parts cost. This could be in the form of a listing approved by Program Management or rigorous pricing backup, as appropriate for the particular contractual phase.

g. A tabulation of the following type of applicable particulars as they become available during design evolvement:

(1) Name, part number, and work breakdown structure number assigned
(2) Quantity per next higher assembly
(3) Quantity per total system
(4) Production unit cost (allocated, estimated, or actual; see f)
(5) Cost as a spare (allocated, estimated, or actual; see f)
(6) Average repair material cost estimate
(7) Number of non-standard parts
(8) Approval status of non-standard parts
(9) Allocated or actual weight
(10) Allocated or actual overall dimensions
(11) Allocated or actual power/fuel consumption
(12) Allocated or actual heat dissipation
(13) Allocated or predicted MTBF
(14) Allocated or predicted MTTR
(15) Allocated or predicted testability FOMs
(16) Other allocated or predicted R/M indices and derate factors
(17) SMR code assigned
(18) Actual manufacturer's name and code
(19) Special handling provisions
(20) Special manpower considerations.

h. A tabulation of performance design characteristics essential to defining electro/mechanical interfaces. Some typical items are

(1) Connector and pin assignments
(2) Signal and test point parameter and tolerances
(3) Transfer characteristics
(4) Voltages, waveshapes, timing, truth tables, impedances, tolerances, etc.
(5) Environmental restrictions and conditioning (i.e., cooling, vibration, damping, etc.)
(6) Structural interfaces

(7) Stress transfers and other mechanical interfaces
(8) Loading requirements (electrical or structural)
(9) Pressures, fluid flows, torques, etc.

3.2.2._._. Preparation. The required information shall be prepared by the cognizant design and support engineers and administered jointly by the engineering and LSA Management functions.

3.2.2._._._. Time phasing. The allocations shall be started at design initiation of an item, entering as much "design to" information or allocations as is required to design/develop the item. The information shall be updated and missing information added as design progresses, to define the item to the degree necessary for design completion and the preparation of engineering drawings and schematics. At that time requirements allocations shall be officially released and configuration controlled in the same manner as the engineering drawings. Controls shall be established by the performing activity to ensure proper approval by engineering and support managers as well as proper distribution to all users of this information prior to design release.

At the time of release to design, all information required may not be available. This may be particularly true of non-performance-related information, such as cost, weight, and results of analyses. This information may then be either estimated, and so indicated, or supplied at a later date. Any updates to this information shall be treated as formally as the original, to ensure that all users have the proper data base. Final update shall be determined by the ILS schedule requirements.

3.3 SYSTEM ENGINEERING MANAGEMENT. The contractor shall establish and maintain a systems engineering management effort in accordance with MIL-STD-499 that coordinates and integrates program requirements, design efforts, specialized engineering disciplines, and related support disciplines throughout the full-scale development phase. This system engineering effort shall result in the definition of the system configuration and related technologies to a detailed level, such that a firm technical base is established from which to enter production.

The contractor shall establish and maintain an environment by senior management personnel that will ensure the success of the reliability, maintainability, and logistics programs. This emphasis shall be communicated through personal involvement, written comments, and participation in major R,M&L and design meetings. The planning for R,M&L must be consistent with the schedule of design activity so that the products of

R&M activities can influence the design by application of ULCE, rather than after-the-fact analyses and documentation. Visibility and control procedures shall be established in consort with QA procedures to ensure that the R&M tasks, including those of the subcontractors, are being accomplished correctly and on time.

3.3.1 Design with computer techniques. The contractor shall aggressively pursue and utilize contemporary, available, *TBD* approved computer techniques for all facets of design, design analyses, producibility analyses, preparation of manufacturing and test procedures, design information transfer to other users, and the preparation of data products.

3.3.2 Design alternative studies. The contractor shall establish and maintain an alternate design trade studies program to pursue an optimum balance between the many demands on system design. This balance shall attach sufficient importance to risk in readiness, supportability, and producibility such that alternatives shall also examine and present for evaluation those design alternatives that would lower these risks, and/or provide improvements over specified requirements at the detriment to other design characteristics. Trade studies shall also be employed to uncover potential design deficiencies. The thrust of the program shall be directed at developing improvements in the baseline design prior to design release. Results of the trade studies shall be available throughout the development program, with the major alternatives presented at the preliminary design review.

3.3.3 Program reviews. The contractor shall plan and conduct both informal and formal technical reviews to assess the degree of completion of technical efforts and the achievement of objectives related to the project milestones. The following formal reviews will be required and shall be conducted at the contractor's site in accordance with MIL-STD-1521, in compliance with the schedule provided in Exhibit __:

a. System Design Review

b. Preliminary Design Review

c. Critical Design Review

d. Functional and Physical Configuration Audits

e. Formal Qualification Review.

The design reviews shall be conducted as an integrated whole that considers all aspects of design and support-related engineering activities. The contractor shall provide an agenda before each meeting in compliance with MIL-STD-1521. The contractor shall

take maximum advantage of utilizing engineering computing equipment involving CAE/CAD/CAM and ULCE to demonstrate that all aspects of the candidate design have been rigorously analyzed and approved by these techniques.

3.3.4 Design risk analyses. The contractor shall institute analysis to assess the risks associated with the design, support, and operational characteristics of the (Contract Item) and shall prepare, maintain, and implement a Risk Management Plan in accordance with MIL-STD-499. The contractor shall develop and implement a technical performance measurement system to support evaluation of system performance, reliability, maintainability, testability, and associated risk. The results of these analyses shall be documented in accordance with 3.1.2.

3.3.5 System effectiveness analyses. The contractor shall verify that (Contract Item) baseline design will meet mission operational, reliability, and availability requirements as defined in the specification, and shall perform cost/performance trades, engineering planning and studies, technology utilization studies, technical risk assessment, and configuration requirements analyses as necessary. The contractor shall perform and document trade studies to support design of a survivable (Contract Item) in the specified operational and maintenance environment. The results of these analyses shall be documented in accordance with 3.1.2.

3.4 HUMAN ENGINEERING MANAGEMENT. The contractor shall establish and conduct a human engineering program in accordance with MIL-H-46855. The contractor shall conduct human engineering program surveillance and control via program reviews, monitoring and controlling subcontractors and vendors, and a data collection, analysis, and corrective action system. These tasks shall be tailored to the development phase of the (Contract Item).

3.4.1 Human Engineering Program Plan. The contractor shall prepare a formal Human Engineering Program Plan in accordance with MIL-H-46855. The program planning and controls shall ensure that appropriate human engineering principles are included in the design of the (Contract item) and all repairable items contained therein. The plan shall include a description of the provisions within the contractor's CAE/CAD process for implementing human engineering principles into the design process.

3.4.2 Human engineering design implementation. This task requires that design rules, as obtained from military specifications, handbooks, and lessons-learned data

be made part of the CAE/CAD rules library to the extent that contemporary computer techniques permit. The design rules shall ensure that the design incorporates human factors and safety features commensurate with specified operational and maintenance scenario requirements. CAE/CAD interactive techniques shall automatically (to the extent possible) analyze the design from the standpoint of work access and other anthropometric considerations. It shall, together with the maintainability analyses, determine the task and skill requirements, as well as training requirements of the maintainer and operator. The analyses shall also assess and identify personnel safety problems such as dangerous voltages, power levels, hazardous tasks, sharp edges, toxic material, etc., to become an interactive part of the human factors analyses.

3.7 RELIABILITY MANAGEMENT. The contractor shall establish and conduct a reliability program in accordance with MIL-STD-785. The contractor shall conduct reliability program surveillance and control in accordance with MIL-STD-785 Task 102 (Monitor and Control of Subcontractors/Vendors), 103 (Program Reviews), and 104 (Data Collection, Analysis, and Corrective Action System), respectively. These tasks shall be tailored to the development phase of the (Contract Item).

3.7.1 Reliability Program Plan. The contractor shall prepare a formal Reliability Program Plan in accordance with MIL-STD-785, Task 101. The program planning and controls shall ensure that appropriate reliability engineering principles are included in the design of the (Contract item). The plan shall include a description of the provisions within the contractor's CAE/CAD process for implementing reliability engineering principles into the design process.

3.7.2 Program reviews. Formal reliability design reviews shall be a part of the regularly scheduled technical reviews. A graphic treatment of trends shall be prepared for program management review. Reviews shall cover all pertinent aspects of the reliability program, such as status, results of reliability-related tasks, documentation of task results, compliance with specified reliability requirements, specific reliability-related design features, and compliance with cost and schedule budgets. The accomplishments during the period covered shall be documented with a treatment of progress on a task-by-task basis. Problems noted, solved, and/or unresolved shall be identified and adequate control established to provide for continual surveillance.

3.7.3 Reliability design implementation. The contractor shall conduct reliability design and evaluation in accordance with MIL-STD-785 Task Section 200 and shall as a minimum perform the following described subtasks

3.7.3.1 Provide design guidance. Design-related reliability requirements shall be given the designer by indoctrinations or written design guides. The reliability requirements shall be

a. Translated into terms that can be related to the designer in terms of guides

b. Input to his computer in terms of rules for rules checking

c. Translated into figures of merit for the quantitative portions of design rules and analytical goals

d. Input into a library of information for use by the design and analyses programs.

3.7.3.2 Reliability allocations. This task shall provide the allocation of the (Contract Item's) quantitative reliability requirements to the module level, as it has been partitioned. Allocation shall narrow the selection of preferred parts, parts rating, and quality level for use in the design of the module. Allocations shall optimize between parts reliability, parts and/or module redundancies, standardization, and cost. Allocation techniques shall be automated to the extent possible with contemporary computer programs. They shall keep running tabs and updates of next higher assembly affects and interact directly with the designer's CAE terminal. As a minimum, selection shall result in automated parts listing to be contained on a drawing's bill of material, as well as provide the listing in text processor format for use in editing into a parts list, maintainability, and LSAR inputs.

3.7.3.3 Equipment design interaction. Automated techniques shall provide for completely interactive design guidance, analyses, and feedback, as well as for automatic optimization between trades of reliability, maintainability, supportability, modularization, performance, weight, volume, and cost. As a minimum, the term "interactive" shall mean the multidirectional transfer of the required information between CAE/CAD and reliability hardware and software in such fashion that manual transcription or keyboarding shall not be required, and the time to analyze, feedback and correct the design fits well into the design schedule.

3.7.3.4 Reliability analyses. The contractor shall use currently available interactive analyses techniques and, to the extent possible, provide interaction with the designer's CAE/CAD. As a minimum, the specified reliability analyses shall be performed as standalone computer program modules that interact with each other as well as the CAE/CAD as defined under "Equipment design interaction." The outputs of the analyses shall provide input to the LSAR. As a minimum, the term "interactive" shall mean the multidirectional transfer of the required information between CAE/CAD and reliability hardware and software in such fashion that manual transcription or keyboarding shall not be required, and the time to analyze, feedback, and correct the design fits well into the design schedule. The analyses shall be the instrument for design approval to the extent provided in the specified QA provisions. Particular attention shall be given the following analyses due to their potential effect on the (Contract Item's) reliability.

3.7.3.4.1 Reliability stress analyses. Automated analytic techniques shall be employed to determine the effect of stress on the performance and reliability of each item being designed. Stress analyses shall range from temperature and mechanical shock to vibration and other mechanical stresses on the components, as well as the chassis or circuit board these are mounted on. As a goal, the stress analyses shall automatically optimize parts placement and application. Detailed design information (as defined under "Equipment design interaction") shall be interactively available to perform the analyses, such as the following:

a. Electrical design and component information for electrical stress analyses and parts application

b. Ambient/cooling air information for thermal stress analyses

c An environmental profile, together with mechanical layout and packaging information for environmental stress analyses.

3.7.3.5 Reliability trades. Reliability trades shall result in optimizing reliability, maintainability, supportability, testability, and other design attributes to attain maximum readiness and sustainability at the lowest life cycle cost to the Government. Trades shall be based on accurate user inputs as concerns the application of equipment, its operational and maintenance scenario, the desired/available support equipment, skills, and training limitations, as well as the Government-supplied input quantifiers for the life cycle cost modeling. These shall accurately fit the situation being modeled and must include the proper overhead costs, to preclude erroneous skewing towards Government labor-intensive

support. Reliability trades shall be performed in the areas that have been identified as potentially resulting in viable, cost-effective reliability improvements as determined by sensitivities exhibited in reliability, maintainability, and life cycle cost analyses. The results of these analyses shall be documented in accordance with 3.1.2.

3.8 MAINTAINABILITY MANAGEMENT. The contractor shall establish and conduct a maintainability program in accordance with MIL-STD-470. The contractor shall conduct maintainability program surveillance and control in accordance with MIL-STD-470 Task 102 (Monitor and Control of Subcontractors/Vendors), 103 (Program Reviews), and 104 (Data Collection, Analysis, and Corrective Action System), respectively. These tasks shall be tailored to the Development Phase of the (Contract Item).

3.8.1 Maintainability Program Plan. The contractor shall prepare a formal Maintainability Program Plan in accordance with MIL-STD-470 Task 101. The program planning and controls shall ensure that appropriate maintainability engineering principles are included in the design of the (Contract item). The plan shall include a description of the provisions within the contractor's CAE/CAD process for implementing maintainability engineering principles into the design process.

3.8.2 Program reviews. Formal maintainability design reviews shall be a part of the regularly scheduled technical reviews. A graphic treatment of trends shall be prepared for program management review. Reviews shall cover all pertinent aspects of the maintainability program, such as status, results of maintainability-related tasks, documentation of task results, compliance with specified maintainability requirements, specific maintainability-related design features, and compliance with cost and schedule budgets. The accomplishments during the period covered shall be documented with a treatment of progress on a task-by-task basis. Problems noted, solved, and/or unresolved shall be identified and adequate control established to provide for continual surveillance.

3.8.3 Maintainability design implementation. The contractor shall conduct maintainability design and evaluation in accordance with MIL-STD-470 Task Section 200 and shall as a minimum perform the following described subtasks.

3.8.3.1 Provide design guidance. Design-related maintainability requirements shall be given the designer by indoctrinations or written design guides. The maintainability requirements shall be

a. Translated into terms that can be related to the designer in terms of guides

b. Input to his computer in terms of rules for rules checking

c. Translated into figures of merit for the quantitative portions of design rules and analytical goals

d. Input into a library of information for use by the design and analyses programs.

Requirements shall be properly tailored and allocated to the equipment from the overall operational maintenance and support concept. Quantitative requirements concerning critical performance, redundancies, built-in-test, etc., shall be ranked in the order of importance and tied to specific performance attributes.

This task shall provide for the influencing of a design such that its maintainability, supportability, and readiness-related design attributes are optimally included in the design features. This task shall also provide the generation and communication of performance information required for preparation of technical manuals as well as the electrical/mechanical design information for that same purpose. Computerized design rules must be provided in such fashion that they are accessible to the computer-aided design program as well as the computerized analytical techniques that will be employed.

3.8.3.2 Maintainability allocations. This task shall provide the allocation of the (Contract Item's) quantitative maintainability requirements to the module level, as it has been partitioned. Allocations shall optimize between functional partitioning, module standardization, and spares cost. Allocation techniques shall be automated to the extent possible with contemporary computer programs. They shall keep running tabs and updates of next higher assembly affects and interact directly with the designer's CAE terminal.

3.8.3.3 Equipment design interaction. Automated techniques shall provide for completely interactive design guidance, analyses, and feedback, as well as for automatic optimization between trades of reliability, maintainability, supportability, mechanical, and electrical packaging, modularization, performance, weight, volume, and cost. As a minimum, the term "interactive" shall mean the multidirectional transfer of the required information between CAE/CAD and maintainability hardware and software in such fashion that manual transcription or keyboarding shall not be required and the time to analyze, feedback to, and correct the design fits well into the design schedule.

3.8.3.4 Maintainability analyses. The contractor shall use currently available interactive analytical techniques and, to the extent possible, provide interaction with the designer's CAE/CAD. As a minimum, the specified maintainability analyses shall be performed as standalone computer program modules that interact with each other as well as the CAE/CAD as defined under "Equipment design interaction." The outputs of the analyses shall provide interactive input to the LSAR. As a minimum, the term "interactive" shall mean the multidirectional transfer of the required information between CAE/CAD and maintainability hardware and software in such fashion that manual transcription or keyboarding shall not be required, and the time to analyze, feedback, and correct the design fits well into the design schedule. They shall also provide the source data for training material, detailed step-by-step procedures for assembly and disassembly, and similar repair actions. Detailed timing diagrams and test point signatures shall also be provided. The repair-level analyses shall constitute the trades necessary to optimize the repair facilities, spares buys and placement, and transportation issues.

3.9 TESTABILITY MANAGEMENT. The contractor shall establish and conduct a testability program in accordance with MIL-STD-2165. The contractor shall conduct testability program surveillance and control in accordance with MIL-STD-2165 Task 101 (Testability Program Planning), Task 102 (Testability Reviews), and Task 103 (Testability Data Collection and Analysis), respectively. These tasks shall be tailored to the Development Phase of the (Contract Item).

3.9.1 Testability program plan. The contractor shall prepare a Testability Program Plan in accordance with Task 101. The program planning and controls shall ensure that appropriate testability engineering principles are included in the design of the (Contract Item). The plan shall also include a description of the provisions within the contractor's CAE/CAD process for implementing testability engineering principles and performance measurement automation, and/or enhancement into the design.

3.9.2 Program reviews. Formal testability design reviews shall be a part of the regularly scheduled technical reviews, shall cover all pertinent aspects of the testability program, such as status, results of testability-related tasks, documentation of task results, compliance with specified testability requirements, specific testability-related design features, and compliance with cost and schedule budgets. The accomplishments during the period covered shall be documented with a treatment of progress on a task-by-task basis.

Problems noted, solved, and/or unresolved shall be identified and adequate control established to provide for continual surveillance.

3.9.3 Testability design implementation. The contractor shall conduct testability design and analysis in accordance with MIL-STD-2165 Task Section 200 and shall as a minimum perform the following described subtasks.

3.9.3.1 Provide design guidance. The contractor shall establish the overall testability design objectives in accordance with Task 201 of MIL-STD-2165, and translate these into design-related testability requirements. These requirements shall be given to the designer by indoctrinations or written design guides. The testability requirements shall be

a. Translated into terms that can be related to the designer in terms of guides

b. Input into his computer in terms of rules for rules checking

c. Translated into figures of merit for the quantitative portions of design rules and analytical goals

d. Input into a library of information for use by the design and analyses programs.

Requirements shall be properly tailored and allocated to the equipment from the overall operational maintenance and support concept. Quantitative requirements concerning critical performance, redundancies, built-in-test, etc., shall be ranked in the order of importance and tied to specific performance attributes. Computerized design rules must be provided in such fashion that they are accessible to the computer-aided design program as well as the computerized analytical techniques that will be employed.

3.9.3.2 Testability design. The contractor shall incorporate testability design practices and testability performance features into the (Contract Item) early in the design phase in accordance with Tasks 202 and 203 of MIL-STD-2165. The contractor shall institute testability design concepts as an integral part of the (Contract Item) design process. Testability design considerations include partitioning (physical, functional, electrical), initialization, module interface, controllability, observability, parts selection, failure mode characterization, electrical partitioning for off-line test, test point selection, and built-in-test hardware, software, and firmware.

3.9.3.3 Equipment design interaction. Testability design shall be interactive with, or an integral part of the CAE/CAD process, to the extent possible, to ensure the inclusion of testability design features and attributes. As a minimum, the term

"interactive" shall mean the multidirectional transfer of the required information between CAE/CAD and testability hardware and software in such fashion that manual transcription or keyboarding shall not be required, and the time to analyze, feedback, and correct the design fits well into the design schedule.

3.9.3.4 Preliminary testability analysis. The contractor shall conduct a preliminary testability analysis to ascertain the inherent testability attributes of the proposed design and to apportion appropriate testability design concepts for the preliminary design of each repairable item, in accordance with Task 202 of MIL-STD-2165 (as determined by the LSA process) of the (Contract Item).

3.9.3.4.1 The contractor shall make maximum use of CAE/CAD tools and design analysis in the performance of the preliminary inherent testability assessment. (The optimum goal is for the CAD/CAE to automatically evaluate inherent testability criteria and provide scoring.) The results of the analysis shall be documented in accordance with 3.1.2.

3.9.3.4.2 The contractor shall submit his preliminary testability analysis methodology, coordination with CAE/CAD, weighting factors, and scoring methodologies for each specified item as part of his proposal.

3.9.3.5 Testability analysis. The contractor shall conduct a Testability Analysis in accordance with MIL-STD-2165 Task 203 for the (Contract Item) as well as each repairable item contained therein, in consonance with the specified maintenance requirements and the approved results of repair-level analyses (if any). Results of the analyses shall be compared to the allocations to ensure that specified testability performance levels have been achieved.

3.9.3.5.1 The contractor shall utilize CAE/CAD fault data as a base for the testability analysis. Automated analytic techniques shall be employed to analyze a circuit to determine whether or not it is testable for all its performance attributes with the test facilities that are resident in the circuit. To the extent possible with contemporary techniques, the analyses shall provide information for test point placement, as well as the development of fault isolation procedures and built-in-test routines. Outputs shall be structured such that they can be applied in digital format to prepare checkout and fault isolation procedures and inputs to the technical manuals and automatic technical information repository.

3.9.3.5.2 The contractor shall submit his testability analysis methodology, coordination with CAD/CAE and the LSA process, as part of his proposal.

3.9.3.6 Testability trades. Testability trades shall result in optimizing reliability, maintainability, testability, supportability, and other design attributes to attain maximum readiness and sustainability at the lowest life cycle cost to the Government. Trades shall be based on accurate user inputs as concerns the application of equipment, its operational and maintenance scenario, the desired/available support equipment, skills, and training limitations, as well as the Government-supplied input quantifiers for the life cycle cost modeling. These shall accurately fit the situation being modeled and must include the proper overhead costs, to preclude erroneous skewing towards Government labor-intensive support. Trades shall also consider the effects on transportability and be modeled in such a way as to interact with the modularization of the equipment being designed, which in turn shall interact with provisioning costs, stocking levels, and warehousing considerations. Testability trades shall be performed in those areas that have been identified as potentially resulting in viable, cost-effective testability improvements as determined by sensitivities exhibited in reliability, maintainability, and life cycle cost analyses. The results of these analyses shall be documented in accordance with 3.1.2.

3.10 INTEGRATED LOGISTIC SUPPORT MANAGEMENT. The contractor shall establish and maintain an integrated logistic support (ILS) program in accordance with the ILS Specification ________. Tasks associated with the design of the (Contract Item) shall be delegated to reliability, maintainability, and human factors engineering, employing a matrix management, in which the ILS management function shares authority and responsibility.

3.10.1 ILS Program Plan. The contractor shall prepare a formal ILS Program Plan in accordance with the ILS Specification ______. The plan shall include a description of the provisions within the contractor's CAE/CAD process for capturing design, reliability, maintainability, and testability data in digital format for transfer to and use in the preparation of LSARs, support resource planning, and acquisition.

3.10.2 Program reviews. Formal ILS design reviews shall be part of the regularly scheduled technical reviews. A graphic treatment of trends shall be prepared for program management review. Reviews shall cover all pertinent aspects of the ILS program, such as status, results of ILS/LSA-related tasks, documentation of task results, compliance with specified ILS/LSA requirements, and compliance with cost and schedule

budgets. The accomplishments during the period covered shall be documented with a treatment of progress on a task-by-task basis. Problems noted, solved, and/or unresolved shall be identified and adequate control established to provide for continual surveillance.

3.10.3 ILS design implementation. The contractor shall translate all (Contract Item) design-related support requirements into commensurate design requirements. These in turn shall be implemented in accordance with their respective, approved program plans.

3.10.4 Assimilation of analyses results. The results of all reliability, maintainability, testability, and human factors analysis shall be placed into a data repository in such manner as to be readily accessible, without translation or keyboarding, to the computer(s) and programs to be used for preparation of the ILS-related analyses, output records, technical manuals, and the specified data products. Computer techniques shall be employed to compare the configuration of the items analyzed and the source of the information of the various analyses that interact with each other and those that are to be combined for the ILS products. The comparison shall be recorded and catalogued in such manner as to provide traceability to design status as well as to flag inconsistencies. Controls shall be implemented to ensure that only configuration consistent design information and analyses results are employed for the ILS products.

(Note to author: The data output format and data dictionary requirements must be specified in the Data Item Description (DID).)

DEFINITIONS

Interactive activities	Interactive activities are activities that, as a minimum, require no transcription of information from one module of computer technique to the other. Timing shall be such as to cause the minimum delay possible to allocate requirements, analyze compliance, feedback corrections, and provide approval of the in-process design. Ideally, if technology permits, the processes occur concurrently with all interactions available to the designer at the CAE terminal.

Appendix D

COUNTERMEASURES SET AN/ALQ-XXX TESTABILITY DESIGN GUIDANCE FOR THE DESIGN ENGINEER

A. GENERAL

1. Affects on Design

Automated Test Equipment (ATE) is a fully automated, computer-operated test system used in checking out and fault isolating line-replaceable units (LRUs) and shop-replaceable units (SRUs). The requirement for compatibility with ATE imposes stringent hardware design restrictions that affect not only design features for testing at the shop level but also design features that affect the operational use of the LRUs. The features may be divided as follows:

- Features affecting equipment division, referred to as modularization.
- Features affecting access interconnections and mounting, referred to as replaceability.
- Features affecting electrical design.

The design features require different considerations for the operational environment, organizational level, and shop environment, intermediate level. The depot level is not separately considered under ATE compatibility requirements because the intermediate-level requirements adequately serve the depot level.

This appendix presents the highlights of the requirements for testability and ATE compatibility, but it should not be deemed all inclusive. Applicable documents are as follows:

- For design constraints affecting modularization, replaceability, fault isolation, and testing
  - MIL-STD-2084: *Maintainability of Avionic and Electronic Systems and Equipment*
- For design constraints affecting electrical design
  - MIL-STD-2076: *Unit Under Test Compatibility with Automatic Test Equipment, General Requirements for*
- For software requirements
  - MIL-STD-2077: *Test Program Sets, General Requirements for.*

B. THE PHILOSOPHY OF AUTOMATED TEST EQUIPMENT COMPATIBILITY

1. Manpower Problems

It has become increasingly difficult for the government to supply the necessary skills to repair today's complex electronic equipment. The necessary training usually demands the major portion of an enlisted man's tour of duty. Within the military, attrition is very high, resulting in a large expense for very little return. Moreover, non-career enlisted personnel seldom display a conscientious, professional attitude towards repair tasks, which leads to maintenance-induced failures. Such failures today outweigh random failures by factors of 4 or 5 for electronic avionics equipment.

The government is therefore requiring that systems be designed to minimize such failures by simplifying maintenance--making fault isolation automatic; making removal and replacement a simple matter, almost like changing tubes; and limiting repair to expensive items.

2. Test Equipment Problems

Because avionics equipment has been required to perform ever increasingly difficult tasks, the testing of the equipment has also become more difficult and more sophisticated, requiring an endless number of special test sets, which rapidly consume available space on bases and depots.

In spite of these complex testing requirements, no major changes in electronics have occurred. Ohm's law still works; the energy spectrum has not changed, digital logic still depends on "ones" and "zeros." Poor packaging concepts prevent testing an assembly as an entity; instead its sister assemblies must be used as signal conditioners, interfaces, etc. Since this concept would soon exhaust spares, the test equipment is usually designed to take the place of the sister assemblies.

The government is therefore requiring that avionics equipment be designed to be tested by fundamental test equipment--equipment requiring no signal conditioners, interfaces, etc. A system must be divisible into independently testable entities that can be tested by basic parameters such as frequency, voltage, power, ones and zeros. Thus a collection of fundamental test equipment will be used to check every item of avionics.

3. Logistics Problems

The same equipment sophistication that caused the manpower and test equipment problems is causing an infinite variety of new components to be created and used by industry. Many are necessary to perform newly developed functions, and many are required to reduce size and weight as well as to enhance reliability. However, these required components are usually outnumbered by new devices that are not absolutely necessary. Consequently, spares inventories are becoming so huge as to become prohibitive. In fact, using components from one avionics system to service another is rare, which causes an inventory problem. Another problem caused by the proliferation of spares is the maintenance-induced failure caused by a technician who cannibalizes from one system for repair of the other, thinking that the similarity between components is adequate. Incompatibility of similar components between one system design and another can be rationalized, but incompatibility of similar components within the same system cannot. The government is therefore requiring some measure of standardization within systems, among parts and circuits.

C. THE DESIGN CONSTRAINTS

1. Modularization

a. At the Organizational Level

All equipment shall be subdivided into line-replaceable units (LRUs) in such a manner that each can be functionally tested by itself. This requires that each contain entire and identifiable functions. Splitting of functions is not permissible.

Further restrictions on LRU modularization are

- Weight of no more that 45 pounds.
- Must be removable from the aircraft by one man within 15 minutes.
- The ratio of LRUs that weigh less that 40 pounds and can be removed within 15 minutes to those that cannot must be greater than 0.90.
- No adjustments or trimming is permitted at the aircraft installation.

The design therefore requires the following considerations:

- Package functionally only.
- Provide rack-and-panel connectors or bayonet connectors. Keep the quantity to a minimum.
- Provide adequate, well-placed handles to facilitate one-man operation.
- Minimize the quantity of fasteners.
- Fasteners should only require standard, simple tools--preferably no tools.
- Consider the environment, temperature, humidity, and working space when planning the fasteners.
- The fasteners should be easily accessible and manipulated.
- If connectors are not rack-and-panel type, design for sufficient cable slack so that connectors can be properly seen and manipulated.
- Provide adequate spacing between connectors to allow for easy manipulation.

b. At the Intermediate Level

All LRUs must be further subdivided into functional shop-replaceable units (SRUs). Functional packaging again is essential as will be seen from electrical considerations.

Further restrictions on SRU modularization are

- The number of different SRUs shall be minimized.
- SRUs shall be plugged into the LRU. The ratio of plugged-in SRUs to those that are not must be greater than 0.90. The latter group includes the chassis and its components and any SRU that must be serviced in place.
- SRUs should be designed to be repairable, so that the customer (via an LOR analysis) can determine the most cost effective way to go.
- Adjustments should be minimized on an SRU upon installation of an SRU into an LRU. If adjustments are necessary they must be simple.

The design, therefore, requires the following considerations:

- Package functionally only.
- Package for plug-in operation only.
- Avoid chassis-mounted components.

- Front panels should also be plug-in if they contain components.
- Package into small, inexpensive subassemblies.

2. Replaceability

a. At the Organizational Level

At this level, the modularization design considerations adequately encompass replaceability. The 15-minute requirement must be carefully considered. Access to the LRU is usually not specified, since it is a function of aircraft design. However, if the equipment is mounted in a contractor-furnished console or other mounting device, access becomes the contractor's responsibility. Consoles, therefore, should be designed such that no disassembly is required to gain access to the LRU. All access must be from the front of the equipment.

b. At the Intermediate Level

At this level, the replaceability is governed by the type and quantity of fasteners employed in the LRU covers, the type and quantity of hold-down devices, and the manner in which the LRU is wired up.

The requirements for replaceability are the same as those for modularization, along with the following:

- Rapid access to the SRU.
- SRUs, components, or wiring shall not be required to be removed to gain access to an SRU or its fasteners.
- Repairable SRUs shall not be conformal coated unless required by design constraints, in which case the coating must be a removable polyurethane type.

The design, therefore, requires the following consideration:

- No stacking of subassemblies, components, or cables.
- Minimize the number of fasteners.
- Use quick fasteners wherever possible.
- Use captive fasteners.
- Provide room for access to the fasteners and subassemblies.
- Employ plug-in construction.

- Restrict the use of conformal coatings on repairable assemblies to an absolute minimum. (Air curing, thixotropic polyurethane adds 30 minutes to the repair time; nonthixotropic may require 8 to 24 hours.)

3. Electrical Design Constraints

a. At the Organizational Level

Electrical design constraints require that the LRU be electrically functionally packaged and that it contain built-in test features. The following apply:

- The system shall provide a "GO/NO-GO" operator indication automatically or manually initiated when the equipment is turned on.
- A malfunctioned LRU shall contain a malfunction indicator, which shall store its indication even with prime power removed. The status indication shall also be remotely indicated, e.g., on the operator's console.
- Failures shall be located to the malfunctioned LRU without any external test equipment and with an ambiguity of less than 3 percent.
- BIT shall detect 98 percent of the failures, of which 99 percent shall localize to the proper LRU.
- Maximum repair time for organization level maintenance shall not exceed 90 minutes.

To meet these requirements, the design requires the following considerations:

- A BIT capability of checking entire functions in their most complex state, to enable checking the status of virtually all of the components. This can usually be accomplished by system end-to-end testing employing modes that exercise all logic states, modulators, feed back loops, and controls. In many controls an extra position may be required to sense the state of the control.
- Acceptance limits are as follows:
  - All parameters shall be monitored within a 10 percent tolerance.
  - All radio frequency (RF) levels shall be monitored within a 3 decibel (dB) tolerance.
- Functional packaging cannot be overemphasized. It is considerably easier to design a BIT on a functional basis, whereby a malfunctioning function is readily identified, than on a basis of another design philosophy. Functional packaging would then immediately yield the LRU containing the function

(e.g., don't split A to D converters, controls and the items being controlled, local oscillators and front ends, forward and reverse loops, etc.).

- BIT must energize latching-type indicators on each LRU, in addition to its other functions.
- Where operator interfaces are part of the system, such as displays, the BIT must provide a readily understood test pattern to the operator.
- Circuit design must carefully consider failure effects. The highest failure rate items must have a definite identifiable affect in performance. Conversely, decoupling circuits must be an insignificant part of the failure rate, since their failure cannot normally be detected.
- BIT must be designed to completely test and fault isolate within 4 minutes. It must be automatic.
- Design must not require any warm-up, since that time is part of the repair time.
- BIT must be self-contained, requiring no external equipment other than prime power or air conditioning.
- Central distribution networks should be avoided; if they must be used, provisions must be made for testing all inputs and outputs by BIT.

b. At the Intermediate Level

At this level of maintenance, both the LRUs and SRUs are repaired. The test equipment is ATE. In an attempt to reduce human error and keep the costs of the system maintenance to a minimum, the restrictions go beyond the necessity to interface with ATE. The restrictions are

- All inputs and outputs including test points must be compatible with the capabilities of ATE. Neither ATE nor the unit under test (UUT) shall be able to be damaged during test.
- No signal conditioning devices shall be required to be employed between the UUT and ATE.
- No additional test equipment shall be required.
- Other than observing the console controls, no operator intervention shall be required in the use of ATE. (Hands-off maintenance.)
- A fault within an LRU shall be isolated to the malfunctioning SRU non-ambiguously as follows:

- - To a single SRU for 90 percent of the MTBF of the LRU.
  - To an ambiguity of two SRUs for 95 percent of the MTBF of the LRU.
  - To a maximum ambiguity of three SRUs.
- A fault shall be isolated within a repairable SRU to its components as follows: (The SRUs are tested alone with a separate program.)
  - For SRUs containing 10 or less components, isolation to two or less components for 50 percent of the MTBF of the SRU. A maximum ambiguity of four components is permitted.
  - For SRUs containing more than 10 components, isolation to four or less for 80 percent of the SRU's MTBF, eight or less for 95 percent of the MTBF, and a maximum ambiguity of 10 components. It should be cautioned that front panels and chassis are also SRUs.
- Test points must terminate at connectors.
- Test points for fault isolation must be contained on the next higher assembly.
- Test points must not affect performance of the circuit being monitored.
- Test points must meet the safety requirements of MIL-STD-454.

The preceding requirements necessitate the following design considerations:

- Functional packaging.
- Compatibility with ATE requires a knowledge of the limitations of the ATE. These are contained in MIL-STD-2076 and are not repeated here. As a general rule, however, the following should be considered:
  - Design to be compatible with commercially available, non-sophisticated test equipment. ATE capabilities generally match the capabilities of most of Hewlett Packard type equipment. It should be cautioned, however, that neither stimuli or measurements can be made in an analog (e.g., continuous) fashion since ATE is digitally controlled. Therefore, the increments available from ATE must be considered.
  - Circuits must be immune to noise and be capable of driving approximately 10 feet of cable.
  - Test points must be decoupled and be short circuit proof.
  - The operator cannot interpret any measurements, since none are available to him; only the computer makes decisions. This may require some built-in logic or peak detectors, amplitude triggers or similar equipment, in situations where measurements, accuracy, or other limitations prevent

ATE from drawing a conclusion as to the acceptability of the measurement performed.

- Connections to ATE must be made via connectors only. Probing is not permitted. The normal input/output connections can be considered as test points during testing. All other test points should be contained on a separate test connector.
- Controlling and controlled circuitry should be contained in the same SRU, unless ambiguity breaking test points are provided on every line.
- Gates required to complete a function shall be completely contained in the same SRU, unless decoupling resistors and ambiguity breaking test points are provided on all lines.
- Serial counters or registers must be completely contained in the same SRU, unless test points are provided between stages.
- Forward and reverse loops must be completely contained in the SRU, unless ambiguity breaking test points are provided to check the loops.
- If an input short would result in ambiguities greater than three SRUs, for an SRU subject to short circuit failures modes, it shall have a decoupling resistor in series with the input, and a test point on the output side of the resistor, lest a switching arrangement be provided to energize and test one subassembly at a time for input shorts. This cannot be overemphasized, since a short circuit is the largest contributor to ambiguous fault isolation.
- Design circuits should avoid operating near marginal states.
- Design should accommodate complete interchangeability, and avoid "select-at-test" construction, and limit adjustments to the SRU level when these are tested separately. This will require careful signal and tolerance budgeting.
- The design should include plans for testing by logical deduction rather than a myriad of measurements. The method is quicker and considerably less subject to error. This can best be accomplished by judiciously assigning the function(s) to be contained within the SRU. The more independent each SRU is, the easier it is to fault isolate merely by deduction, which ATE is capable of doing. (The resources of the computer are available for this.) Several different functions influencing a single other function should be planned to be permutated during testing to ascertain their operability by measuring the effects of each, singularly, at the output; requiring therefore no test points other than input and output connections.

- Repairable subassemblies must be subdivided into stages commensurate with the permissible ambiguities. Series stages shall contain test points between them.
- Chassis-mounted components should be avoided.
- Voltage dividers should be designed into test points where high voltages are being measured to preclude safety problems.
- Detectors should be employed where possible, to ascertain the status of RF signals to avert RFI problems; however, MTBF should not be sacrificed. Trade-offs should favor reliability, since ambiguity is a function of MTBF.

D. AUTOMATED TEST EQUIPMENT PROGRAMS

The instructions to the ATE for checkout and fault isolation of each LRU and SRU are prepared by the contractor. The instructions are ultimately in the form of a computer program but are developed as required by the specifications in the following systematic manner:

- A functional block diagram is prepared defining functional subdivision. The block diagram will be expanded to define signal budgets and tolerances.
- An interconnection diagram is prepared defining precisely the interconnecting wires, connectors, and connector pins.
- A test strategy is developed defining the interfaces with ATE.
- A formal compatibility report is prepared defining the UUT, its input and output tolerances, and interfaces with ATE as well as measurement tolerances, performance description, and all quantitative parameters such as ambiguity ratios, repair times, and MTBF.
- A thorough checkout and fault isolating routine is prepared in logical flow format to completely test the UUT and fault isolate to the next lower level of assembly (if the UUT is repairable). This diagnostic flow chart (DFC) includes all the set-ups, patching, measurements, and decisions to be made by the ATE in a step-by-step manner requiring no further interpretation.
- A set of diagrams showing the interconnections and patching required for each set-up of ATE called for by the DFC is prepared.
- The DFC is translated into an English language computer program, which specfies the measurements, set-ups, patching, decision, accept/reject criteria, and branching information.

- A magnetic tape, machine language program is prepared from the English language program. This is usually prepared by the procuring activity.

E. TESTING COMPLIANCE WITH SPECIFICATIONS

All quantitative requirements are contained in the compatibility report, which is subject to review and approval by the procuring activity. Repair times are calculated by detailed analysis of each incremental repair task. This analysis is also subject to review and approval.

The test program is checked by deliberate fault insertion at randomly selected decision points to ascertain that the decision points can be reached by ATE. Corrections to the program are the contractor's responsibility. Since the tests obviously cannot be made until a considerable time after delivery (one year after delivery), any program rewrites or hardware redesign can be prohibitively expensive.

Deliberately designing for ATE compatibility must therefore be as conscientiously conducted as is designing to meet system performance criteria.

Appendix E

LOGISTICS SUPPORT COST MODEL
USERS HANDBOOK

JUNE 1975

PREFACE

1. This user's handbook describes the general AFLC Logistic Support Cost (LSC) Model program. The form of this model is general purpose in content, is not appropriate for all systems and cost elements, and must be modified for use on particular systems and equipment.

2. The model is furnished for information only. The model does not represent Air Force policy and should not be used to construe AFLC management systems, methods, or policy. The user will assume full responsibility for any results derived from the application of the model and in no way infer that the model source establishes credibility in the derived results.

3. The application of modified versions of this model for individual Air Force programs will be specified through other documents and agreements. Modifications to the model and guidance on data preparation will be tailored to individual programs. No similarity to the attached model is claimed.

4. The basic model program is written for use by the Air Force on Air Force computers. Access to these computer systems for nongovernment users cannot be provided nor is assistance of a programming nature available to execute this model on other computer systems.

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I. INTRODUCTION:

A fundamental reason for the involvement of AFLC activities during the acquisition of weapon systems, subsystems and equipment is to influence the design process to help insure the production of systems and hardware which will satisfy operational requirements for the lowest total cost of ownership to the government. The Integrated Logistics Support concept (DODD 4100.35 and AFR 800-8) was formulated to promote this policy as well as to insure the concurrent development and production of economical and responsive support systems. The Logistics Support Analysis (MIL-STD-1388) is the single analytical logistic effort within the systems engineering process.

An Integrated Logistics Support Organization (ILSO) is established in each program or projects office (PO) at the AFSC Product Divisions to enhance the integration of support requirements during the life cycle of the system/equipment. The ILSO, headed by a Deputy Program Manager for Logistics (DPML), is responsible to assist the PO in performing life cycle cost and logistics support cost analyses for a defense system throughout the acquisition phase. AFLC personnel must:

(1) Carefully examine basic requirements, including performance requirements, to insure that the logistics impact has been adequately considered.

(2) Maintain visibility of the expected downstream logistics impact in the form of logistics support cost for each of the design requirements or design alternatives as well as changes to requirements as the design evolves.

(3) Make cost of ownership a primary consideration using logistics support cost analytical techniques as basic elements of a totally integrated approach.

To assist the DPML and other program management personnel in the performance of their duties, the Logistics Support Cost (LSC) Model was developed as a tool for computing estimates of expected support costs which might be incurred by adopting a particular design or choosing a certain design alternative. The computerized model consists of ten mathematical equations, each of which describes a portion of the resources required for an operating logistics system.

The purpose of this handbook is to describe and explain the model so that it may be a practical tool for use by personnel in the ILSO and their supporting personnel in the Air Logistic Centers.

II. MODELING OVERVIEW:

What is a Model? For our purpose, a model is a vehicle for arriving at a well-structured view of reality. It is an abstract representation of a physical situation which describes the logic and relationship between elements defining a given process. Models help put the complexities and possible uncertainties inherent in a decision-making problem into a logical framework amenable to comprehensive evaluation. Such a model clarifies the decision alternatives and their anticipated effects, indicates the data that are relevant for analyzing the alternatives, and leads to informative conclusions.

A model is an aid in the decision-making process. However, models, while usually considering the relevant quantitative factors, do not

necessarily consider all qualitative factors which may affect the decision. Management decision-making remains largely a subjective process. Modeling is a means to inject an objective basis into the decision process. As such, models are an aid, not a replacement for human decision-making.

Types of Models. The mathematical models used in management science are of two main types characterized by the methodology employed:

(1) Simulation Model - Simulation models are appropriately utilized for systems characterized by large data bases or sizable solution sets. They are used to analyze situations that are just too complex for analytical models to handle. Simulation models operate on the functional relationships between elements of the system being studied. Solutions are not normally obtained as point estimates, but rather as intervals containing the correct answer subject to statistical variation.

(2) Analytical Model - Analytical models yield a single answer for any given set of values of input data. While the number of parameters is not restricted, an analytical model is often characterized by straight-forward mathematical techniques and a minimal amount of computational effort. The LSC Model described herein is an analytical model of the kind known as accounting models.

III. DESCRIPTION OF THE MODEL:

General: The LSC Model is a method to estimate the expected support cost that may be incurred by adopting a particular design.

The model is used to compare and discriminate among design alternatives where relative cost difference is the desired figure of merit. The significance of the results, therefore, is not based on the absolute value of support costs but on the magnitude of the cost difference between two alternatives. In this regard, the LSC Model is not, strictly speaking, a life cycle cost model although it is one of the many specialized models used to support the technique known as life cycle costing.

The LSC Model is intended for application in three different areas:

(1) To obtain an estimate of the differential logistics support costs between the proposed design configurations of two or more contractors during source selection.

(2) To establish a baseline for contractual commitments on certain aspects of operational supportability which will be subject to verification.

(3) To use as a decision aid in discriminating among design alternatives during prototyping or full-scale development.

Tailoring the model may require eliminating or adding certain equations or variables. For example, equations 9 and 10 are not appropriate when dealing with systems or equipment which do not have engines. On the other hand, if a new resource category (such as software) is known or has the potential to contribute significantly to a logistic support cost determination, it should be incorporated into the model. In many instances, it is appropriate to substitute or redefine certain variables. For example, on a program where the factor

which generates failures or maintenance actions is not flying hours, the proper factor should be used; such as, operating hours, number of sorties, hours on alert, etc.

There are certain assumptions which formed a basis for the development of the LSC Model which must be considered and understood when analyzing and interpreting the results of the model:

(1) The model considers a uniform level of program activity (e.g., flying hours) at each base of operation.

(2) The spares stock level and pipeline quantities are computed to support the peak level of program activity rather than any incremental buildup.

(3) The model explicitly computes only those logistics support costs associated with the weapon system, system, and First Line Unit (FLU) indenture levels.[1] Components below FLU level are only implicitly considered by their relationship to repair of a given FLU.

(4) There is one depot repair location and any specified number of intermediate (base-level) repair locations.

(5) The relationship established for determining the required quantities of Support Equipment (SE) assumes a manhour/machine-hour equivalence. This supposes that a given piece of SE is occupied during the entire elapsed time period equivalent to the manhours required to perform a task. The machine capability is further constrained by the

---

[1] Appendix 1 contains a discussion of the use of the terms system and First Line Unit in the LSC Model.

established work schedule for the maintenance activity. Quantities of SE are also computed which support the peak level of program activity.

(6) The contractor's estimate of the cost to train a maintenance man will be his price for Type I training which is assumed to be the government's cost to provide follow-on training.

(7) Certain elements of resource consumption are not included which certainly contribute to life cycle logistic support cost but for which there is no basis of estimating or evaluating a discernible difference among alternatives. Examples are modification costs, maintenance actions generated by false removals, and replacement of items condemned at the depot as a result of policy.

The model has been programmed in FORTRAN for the AFLC Computational Resources for Engineering and Simulation, Training, and Education (CREATE) system. The CREATE system provides for either a time-sharing or batch mode of operation using the terminals at HQ AFLC, each ALC and AQ resident directorates, and certain other locations.

Data. There are 94 data elements which form the basis for the mathematical relationships in the model. The data elements and the variable names assigned to them are defined in Appendix 2. These elements can be divided into five categories which identify the nature and origin of the data:

(1) Program Elements. Obtained from the scenario written from the operational concept of the weapon system. These elements relating to flying or operating hour programs, deployment, operating locations and weapon system standards are furnished by the government, usually the System Program Office.

(2) Contractor-Furnished System Elements. Furnished by the contractor based on his design experience. These costs are not allocated to component FLUs but contribute to overall system-level cost.

(3) Contractor-Furnished FLU Elements. Furnished by the contractor based on the characteristics of his design configuration. Some of this information may have evolved from comparison and projection of operational experience on existing systems obtained from AFM 66-1 data.

(4) Propulsion System Elements. For those weapon systems with propulsion systems, there are certain data elements which must be supplied. The government provides those elements dealing with base/depot repair cycle time, resupply and build-up time and fuel costs. The contractor furnishes the elements related to engine unit costs and performance.

(5) Government-Furnished Standard Elements. There are several cost and time standard elements such as labor rates, inventory costs and repair-cycle times which are furnished by the government.

The DPML should be the focal point in the effort to evaluate data which are used in logistics models. He must obtain and furnish to contractors those data elements which the government is required to provide. Data originated by contractors must be carefully reviewed and assessed to assure they are reasonable and consistent. Historical data on similar, existing Air Force equipment, if available, may assist this effort. Contractor rationale should be required to support significant improvements in historical performance or state-of-the-art breakthroughs.

In exercising the model, the government-furnished standard data should normally be used as provided without change. These data have been developed from historical cost-accounting information and special studies and will be updated by the responsible agencies as required. However, if a certain standard is clearly seen to be inappropriately valued and which would bias the LSC analysis, the DPML may obtain approval from the originator to change it.

Perhaps the most significant variable in the LSC Model is the reliability parameter of FLUs which appears in seven of the equations. In the basic model this is shown as MTBF - Mean (operating) Time Between Failures. Other forms of this parameter, such as Mean Time Between Maintenance Actions (MTBMA) or Mean Time Between Demands (MTBD) might be used depending on a particular tailoring of the model and the intended application. For example, for use in tradeoff analysis, MTBMA is probably most appropriate in order to consider and account for the maximum incurrences of cost. However, in a situation such as contractor source selection, where logistics supportability cost commitments or warranty provisions are established and a precise, enforceable definition of terms is mandatory, the MTBF parameter is more appropriate.

Equations. The basic LSC Model consists of ten equations or submodels, each of which represents a cost of resources necessary to operate the logistics system. The first eight equations are structured to aggregate the cost of each system within the weapon system including the subordinate FLUs and support equipment. Equations 9 and 10 compute

costs unique to the propulsion system but are kept separate for visibility purposes. The final result is simply a summation of the individual equations across all systems. The equations are shown and explained in Appendix 3.

Results. The result of the effort to collect data and exercise the model is an estimate of the expected logistics support costs that might occur for a particular design configuration. The Air Force must evaluate the results and identify specific equipment characteristics contributing to potentially excessive support costs.

LSC is an important factor in determining the selection of a contractor when more than just acquisition costs are considered. The model provides information to the program manager and AFLC on the expected cost to support a defense system throughout its operational life.

The responsibility of the DPML, as the representative of AFLC, is to inform the program manager of the impact of decisions affecting logistics based on the estimated costs to support the system.

IV. APPLICATION

General Implementation Instructions. Logisticians assigned to the ILSO are the primary users of the LSC Model and will analyze the results. They are responsible to supply necessary and correct program related data and government standards to contractors and to advise which data elements must be furnished by contractors. Validation of estimated equipment characteristics may require additional support from ALC Equipment Specialists, Item Managers and Service Engineering personnel.

The DPML should furnish the basic LSC Model computer program to contractors. The basic model, as programmed, should be used as a framework for analysis and the basic philosophy embodied in the model should not be changed. However, changes to the basic model are permitted to tailor the model to a specific program. Direct analytic support and advice on the model application will be provided by the Resident Acquisition Logistics Directorate (AFLC/AQA/AQE/AQS). AFLC/AQMLE may also be requested to provide guidance or an evaluation in certain cases and to resolve questions of basic policy or philosophy regarding the model.

Contractors will have questions and comments regarding the philosophy and mechanics of operating the model. The ILSO should be able to respond to questions, to recommend to the contractor the proper application of data, and to generally assist him in operating the model. The only direct communication and exchange of data with contractors should be made through the Program Office/DPML.

The following sections will describe the techniques for exercising the LSC Model using the CREATE computer. However, it is not the purpose of this handbook to provide basic instruction about the CREATE system or about the programming language used for the model (FORTRAN). All of the programs and files described herein have general read permission.

Time-Sharing Mode. The model can be exercised in a time-sharing (TSS) mode on a CREATE remote terminal. The prerequisites for operation are (1) transfer of the LSC Model program to your current file and (2) establishment of your data file(s). Instructions for

building a data file are contained in a later section.

The TSS source version of the basic model exists under USERID AQM with filename TSSMOD. To access the program, the TSS question/ answer sequence is:

```
SYST? FORT
OLD OR NEW - OLD AQM/TSSMOD,R
READY
*
```

The model is then available on your current file to use as is or to make modifications as appropriate. Your version of the model should be assigned a unique filename and saved under your own USERID. TSSMOD itself does not have write permission and can be modified only by HQ AFLC personnel.

If your user master catalog contains a file for the model program and a properly formatted data file, the model can then be exercised by the following command: (In the examples which follow, suppose your assigned model filename is XXXLSC and the data filename is XXDATA.)

```
*RUN XXXLSC#XXDATA"10"
```

The program will then compute and display the total LSC for the weapon system followed by an interactive question/answer sequence to provide the information desired by the user.

Batch Mode. The LSC Model can be exercised in the batch mode via punched cards or by using the CARDIN subsystem on a TSS remote terminal. Since most locations, including the ALCs, do not have a card-reading capability, only the CARDIN method will be discussed.

The source version of the basic model for batch use exists under USERID AQM with filename BATCHMOD and is the appropriate form of the model for CARDIN use. This file contains the LSC Model program preceded and followed by the necessary GECOS control cards. As in the time-sharing mode, a data file must also be established.

BATCHMOD may be transferred to your current file in the same manner as TSSMOD.

```
SYST? CARD
OLD OR NEW OLD AQM/BATCHMOD,R
READY
*
```

The framework of BATCHMOD is as follows:

```
0010##NORM
0020$:IDENT:(Your problem number and identification)
0030$:FORTY:NDECK
0040$:LIMITS:,30K
0050
.
.
.
.
.
3630
3640$:OPTION:FORTRAN,NOMAP
3650$:EXECUTE
3660$:LIMITS:,30K
3670$:DATA:05
```

Having accessed BATCHMOD, the main program (lines 50-3630) may be modified as necessary and saved with a unique filename under your USERID.

The $IDENT line must be changed to add the required information. To run a batch job, first concatenate the program file (XXXLSC) with the data file (XXDATA) and give the RUN command:

*OLD XXXLSC;XXDATA

*RUN

Building a Data File. A direct access file containing values for the data elements must be created which is then linked with the model program during execution. The LSC Model programs described herein incorporate some features of an enhanced version of FORTRAN which permits the reading of data in a variable or "free" format and greatly facilitates the inputting of a large data file. Also, the use of CHARACTER statements facilitates the reading of long strings of alphanumeric data. (Note: Be sure to enclose data elements which contain imbedded blanks within quotation marks, such as a two-word noun description.) The required sequence for the data is shown in Appendix 4. Line numbers must be included. The data fils can be built under any system such as FORTRAN or CARDIN. Each "card" of data must be represented by one line in the data file and the prescribed sequence must be followed exactly. There must be a non-blank value for each and every variable in the READ statements. Zeroes must be included where appropriate.

There are five levels of data in the data file and the order of input is according to the following hierarchy:

a. Weapon System data
b. Propulsion System peculiar data
c. System data

d. FLU data

e. SE data

The sequence of lines or "cards" in the data file is as follows. Cards 1, 2, and 3 contain the weapon system data. Propulsion system peculiar data, if applicable, are contained on cards 4 and 5. System data is contained on four cards, so cards 6, 7, 8, and 9 contain data for the first of the NSYS systems. (Note: If the weapon system being analyzed has a propulsion system, that system must be the first system.) FLU data are contained on four cards, so cards 10, 11, 12, and 13 contain data for the first of the N FLUs within the first system. FLU data cards are followed by data on peculiar SE associated with that FLU. Each item of SE requires one card, so if the first FLU within the first system requires an item of peculiar SE, those data are contained on card 14.

There must be four cards of data for each of the NSYS systems, four cards for each of the N FLUs within each system, and one card for each of the K items of SE associated with each FLU. A typical file of data may appear as follows:

Lines (cards)	Variables
1-3	Weapon System
4-5	Propulsion System Peculiar
6-9	System #1 (Propulsion)
10-13	FLU #1-1
14	SE #1-1-1
15	SE #1-1-2
16-19	FLU #1-2
20-23	FLU #1-3
24-27	System #2
28-31	FLU #2-1

Lines (cards)	Variables
32-35	FLU #2-2
36	SE #2-2-1
37	SE #2-2-2
38	SE #2-2-3
39-42	FLU #2-3

Having built a data file on your current file at the terminal, it should be saved in your catalog for further use.

Prior to using a new data file, it is advisable to carefully check it for input errors of character and sequence. There is a program with GECOS control cards called FILEDIT written to assist in this effort. This program when exercised with a given file will echo each value coupled with the name of the variable and perform certain logic checks on the data. FILEDIT may be accessed as follows:

```
SYST? CARD
OLD OR NEW-O AQM/FILEDIT,R
READY
*
```

The framework of FILEDIT is as follows:

```
0010##NORM
0020$:IDENT:(Your problem number and identification)
0030$:FORTY:NDECK
0040$:LIMITS:,26K
0050
.
.
.
.
0900
0910$:OPTION:FORTRAN,NOMAP
0920$:EXECUTE
```

0930$:LIMITS:,8K

0940$:DATA:05

If you have made changes to the READ and PRINT statements in the basic LSC Model program, corresponding changes must be made to the FILEDIT program. The program is run with a concatenated data file as described before for BATCHMOD:

*OLD FILEDIT;XXDATA

*RUN

Output Products. The output available from exercising the computer model is displayed in several forms. In a time-sharing mode, the total logistics support cost is given followed by up to nine optional forms of information which are explained as follows:

Option #1. The total weapon system LSC is broken out among the ten equations.

Option #2. All systems are ranked in decreasing order of total cost. The system identification, its total cost and percentage of total LSC are given.

Option #3. Total cost for a specified system is broken out among the ten equations.

Option #4. A specified number of FLU are ranked by cost (high value first) for a specified system. The FLU identification, its total cost and percentage of system cost are given.

Option #5. Total cost for a specified FLU is broken out among the first seven equations.

Option #6. A detailed SE analysis is given. Each line item of SE in the system is listed along with the computed fractional quantities required (base and depot) and the integerized total requirements.

Option #7. A detailed spares analysis is given showing the stock level, pipeline, and condemnation replacement quantities required for whole engines and FLUs.

Option #8. A detailed maintenance generations analysis is given showing the peak and total FLU maintenance generations both on- and off-equipment.

Option #9. A FLU work unit code and noun description cross-reference is provided.

In the batch mode, all of the information is provided with each run. Other forms of analysis and output may be incorporated as required.

V. EXAMPLE

This section will present an example of using the CREATE computer programs to exercise the LSC Model. The figures referenced are contained in Appendix 5.

A body of data named TESTDATA was built and stored in a direct access file in catalog AQM. The data are for a hypothetical aeronautical weapon system consisting of four systems, including a propulsion system (23000). Each system contains several FLU and SE items. An echo printout of a portion of TESTDATA is shown in Figure 1. To facilitate proofreading and editing this data file, the program FILEDIT was run. Some of this output is displayed in Figure 2.

Having verified TESTDATA, the time-sharing version of the LSC Model, TSSMOD, was used. The results are shown in Figure 3. As can be seen, the total LSC for the system is 2.99 billion. After asking for the explanatory table of available options, Option 1 was used to obtain a breakout of total LSC. The four systems were ranked (Option 2) and a

cost breakout for subsystems 23000 and 74000 was requested (Option 3). Option 4 ranked the top five LRUs in subsystem 23000. Cost breakouts for FLU 23ABO and 23ABA were given in Option 5.

Options 6, 7, 8, and 9 were used to obtain the desired information. No further analysis was desired and the program was terminated.

The program BATCHMOD was used to run the LSC Model in the batch mode using the same data file, TESTDATA. Samples of this output are shown in Figure 4.

Annex 1

DESCRIPTION OF TERMS
SYSTEM AND FIRST LINE UNIT

The basic LSC model is structured to look at a complete weapon system, such as an aircraft, a missile, or a ground CEM system, which has one or more subordinate major functional "systems." Our usage of the term "system" is consistent with that in Military Specification MIL-M-38769A (USAF) which prescribes the assignment of Work Unit Codes to hardware. A system is usually identifiable by the first two digits of the Work Unit Code (WUC). Typical systems on an aircraft weapon system and their WUCs might include:

Airframe	11000
Power Plant	23000
UHF Communications	63000
Fire Control	74000

A First Line Unit (FLU) is the first level of assembly below the system level that is carried as a line item of supply at base level and is usually the highest level of assembly that is removed and replaced, as a unit, on the complete system or subsystem in order to return the equipment to an operational condition. A FLU is assigned a unique WUC and is normally the first, second, or third level of assembly below major system as described in MIL-M-38769A (USAF).

As a rule, removal, replacement, testing, adjustment, in-place repair, or other on-equipment maintenance actions on FLUs can be accomplished by organizational or flightline maintenance personnel without the requirement for special shop support equipment other than portable type test or repair equipment. A lower level subassembly within a FLU, often called a Shop Replaceable Unit, that is replaced or repaired only within base (intermediate level) shops is not defined as a FLU.

In this context, a FLU may be a Line Replaceable Unit in an airborne avionics system (e.g., Radar Navigation Receiver-Transmitter), a mechanical unit in a landing gear system (e.g., Nose Gear Actuator), an engine module in a powerplant system (e.g., Fan Dirve Turbine Module), or a printed circuit module in a ground electronics unit. A large, multipurpose test set, such as an Avionics Intermediate Shop, might be treated as one of the systems in which case, its subordinate modules, drawers, etc. could be treated as FLUs.

Annex 2

LSC MODEL DATA ELEMENTS

Note: (C) = contractor-furnished

(S) = government-furnished standard value

(P) = government-furnished program-peculiar value

Weapon System Variables

1. EBO - Standard established for expected backorders — the expected number of unfilled demands existing at the lowest echelon (bases) at any point in time. (P)

2. IMC - Initial management cost to introduce a new line item of supply (assembly or piece part) into the Air Force inventory. (S = $40.91/item)

3. M - Number of operating base locations. (P)

4. MRF - Average manhours per failure to complete off-equipment maintenance records. (S = .24 hours)

5. MRO - Average manhours per failure to complete on-equipment maintenance records. (S = .08 hours)

6. NSYS - Number of systems within the weapon system. (C)

7. OS - Fraction of total force deployed to overseas locations. (P)

8. OSTCON - Average order and shipping time within the CONUS. (S = .36 months)

9. OSTOS - Average order and shipping time to overseas locations. (S = .53 months)

10. PFFH - Peak Force Flying Hours — expected fleet flying hours for one month during the peak usage period. (P)

11. PIUP - Operational service life of the weapon system in years. (Program Inventory Usage Period) (P)

12. PMB - Direct productive manhours per man per year at base level (includes "touch time", transportation time, and setup time.) (S = 1500 hours/man/year)

13. PMD - Direct productive manhours per man per year at the depot (includes "touch time", transportation time, and setup time.) (S = 1500 hours/man/year)

14. PSC - Average packing and shipping cost to CONUS locations. (S = $0.53/pound)

15. PSO - Average packing and shipping cost to overseas locations. (S = $0.99/pound)

16. RMC - Recurring management cost to maintain a line item of supply (assembly or piece part) in the wholesale inventory system. (S = $104.20/item/year)

17. SA - Annual base supply line item inventory management cost. (S = $20.20/item/year)

18. SR - Average manhours per failure to complete supply transaction records. (S = .25 hours)

19. TD - Average cost per original page of technical documentation. The average acquisition cost of one page of the reproducible source document (does not include reproduction costs.) (S = $220.00/page)

20. TFFH - Expected Total Force Flying Hours over the Program Inventory Usage Period. (P)

21. TR - Average manhours per failure to complete transportation transaction forms. (S = .16 hours)

22. TRB - Annual Turnover rate for base personnel. (S = .33)

23. TRD - Annual turnover rate for depot personnel. (S = .15)

Propulsion System Peculiar Variables

1. ARBUT* - Engine Automatic Resupply and Buildup Time in months. (P)
2. BP* - Base engine repair cycle time in months. (P)
3. CMRI* - Combined Maintenance Removal Interval. Average engine operating hours between removals of the whole engine. (C)
4. CONF - Confidence factor reflecting the probability of satisfying a random demand for a whole engine from serviceable stock to replace a removed engine. (S = 0.90)
5. DP* - Depot engine repair cycle time in months. (P)
6. ENRTS - Fraction of removed whole engines which must be returned to the depot for repair/overhaul. (C)
7. EOH - Average cost per overhaul of the complete engine at the depot expressed as a fraction of the engine unit cost (EUC) including labor and material consumption. Repair and stockage of engine components considered elsewhere as FLUs is not included. (C)
8. EPA - Number of engines per aircraft. (C)
9. ERMH - Average manhours to remove and replace a whole engine including engine trim and runup time. (C)
10. EUC - Expected Unit Cost of a whole engine. (C)
11. FC - Fuel cost per unit. (S = \$0.354/gallon for JP4; \$0.367/gallon for aviation gas)
12. FR - Fuel consumption rate of one engine in units per flying hour. (C)
13. LS - Number of stockage locations for spare engines. (P)

* Reference AFM 400-1, Volume I, Chapter 7 and Atch 1 for complete description of the Engine Pipeline (Flow Cycle) and use of these terms.

System Variables

1. BCA - Total cost of <u>additional</u> items of common base shop support equipment per base required for the system. (C)

2. BAA - Available work time per man in the base shop in manhours per month. (S = 168 hours)

3. BLR - Base labor rate. (S = $11.70/manhour)

4. BMR - Base consumable material consumption rate. Includes minor items of supply (nuts, washers, rags, cleaning fluid, etc.) which are consumed during repair of items. (S = $2.28/hour)

5. BPA - Total cost of peculiar base shop support equipment per base required for the system which is not directly related to repair of specific FLUs or when the quantity required is independent of the anticipated workload (such as, overhead cranes and shop fixtures).

6. CS - Cost of software to utilize existing Automatic Test Equipment for the system. (C)

7. DCA - Total cost of <u>additional</u> items of common depot support equipment required for the system. (C)

8. DAA - Available work time per man at the depot in manhours per month. (S = 168 hours)

9. DLR - Depot labor rate. (S = $12.44/manhour)

10. DMR - Same as BMR except refers to depot level maintenance. (S = $6.72/hour)

11. DPA - Same as BPA except relates to depot support equipment. (C)

12. FB - Total cost of new base facilities (including utilities) to be constructed for operation and maintenance of the system, in dollars per base. (C)

13. FD - Total cost of new depot facilities (including utilities) to be constructed for maintenance of the system. (C)

14. FLA - Total cost of peculiar flight-line support equipment and <u>additional</u> items of common flight-line support equipment per base required for the system. (C)

15. H - Number of pages of depot level technical orders and special repair instructions required to maintain the system. (C)

16. IH - Cost of interconnecting hardware to utilize existing Automatic Test Equipment for the system. (C)

17. JJ - Number of pages of organizational and intermediate level technical orders required to maintain the system. (C)

18. N - Number of different FLUs within the system. (C)

19. SMH - Average manhours to perform a scheduled periodic or phased inspection on the system. (C)

20. SMI - Flying hour interval between scheduled periodic or phased inspections on the system. (C)

21. SYSNOUN - Name of the system — up to 60 alphanumeric characters. (C)

22. TCB - Cost of peculiar training per man at base level including instruction and training materials. (C)

23. TCD - Cost of peculiar training per man at the depot including instruction and training materials. (C)

24. TE - Cost of peculiar training equipment required for the system. (C)

25. XSYS - System identification. The assigned five-character alphanumeric Work Unit Code of the system. (C)

FLU Variables

1. BCMH - Average manhours to perform a shop bench check, screening, and fault verification on a removed FLU prior to initiating repair action or condemning the item. (C)

2. BMC - Average cost per failure for a FLU repaired at base level for stockage and repair of lower level assemblies expressed as a fraction of the FLU unit cost (UC). This is the implicit repair disposition cost for a FLU representing labor, material consumption, and stockage of lower indenture components within the FLU (e.g., shop replaceable units or modules). (C)

3. BMH - Average manhours to perform intermediate-level (base shop) maintenance on a removed FLU including fault isolation, repair, and verification. (C)

4. BRCT - Average Base Repair Cycle Time in months. The elapsed time for a RTS item from removal of the failed item until it is returned to base serviceable stock. (S = .13 months)

5. COND - Fraction of removed FLUs expected to result in condemnation at base level. (C)

6. DMC - Same as BMC except refers to depot repair actions. (C)

7. DMH - Same as BMH except refers to depot-level maintenance.

8. DRCT - Average Depot Repair Cycle Time in months. The elapsed time for a NRTS item from removal of the failed item until it is made available to depot serviceable stock. (S = 1.84 months for organic repair; 2.25 months for contract repair.)

9. FLUNOUN - Word description or name of the FLU — up to 60 alphanumeric characters. (C)

10. IMH - Average manhours to perform corrective maintenance of the FLU in place or on line including fault isolation, repair, and verification. (C)

11. K - Number of line items of peculiar shop support equipment used in repair of the FLU. (C)

12. MTBF - Mean Time Between Failures in operating hours of the FLU in the operational environment. (C)

13. NRTS - Fraction of removed FLUs expected to be returned to the depot for repair. (C)

14. PA - Number of new "P" coded reparable assemblies within the FLU. (C)

15. PAMH - Average manhours expended in place on the complete system for Preparation and Access for the FLU; for example, jacking, unbuttoning, removal of other units and hookup of support equipment. (C)

16. PP - Number of new "P" coded consumable items within the FLU. (C)

17. QPA - Quantity of like FLUs within the parent system. (Quantity per Application) (C)

18. RIP - Fraction of FLU failures which can be repaired in place or on line. (C)

19. RMH - Average manhours to fault isolate, remove, and replace the FLU and verify restoration of the system to operational status. (C)

20. RTS - Fraction of removed FLUs expected to be repaired at base level. (C)

21. SP - Number of standard (already stock-numbered) parts within the FLU which will be managed for the first time at bases where this system is deployed. (C)

22. UC - Expected unit cost of the FLU at the time of initial provisioning. (C)

23. UF - Ratio of operating hours to flying hours for the FLU. (Use Factor) (C)

24. W - FLU unit weight in pounds. (C)

25. XFLU - FLU identification. The assigned five-character alphanumeric Work Unit Code of the FLU. (C)

Support Equipment Variables

1. BUR - Combined utilization rate for all like items of support equipment—base level. (C)
2. CAB - Cost per unit of peculiar support equipment for the base shop. (C)
3. CAD - Same as CAB except refers to depot support equipment. (C)
4. COB - Annual cost to operate and maintain a unit of support equipment at base level expressed as a fraction of the unit cost (CAB). (C)
5. COD - Same as COB except refers to depot support equipment. (C)
6. DOWN - Fraction of downtime for a unit of support equipment for maintenance and calibration requirements. (C)
7. DUR - Same as BUR except refers to depot support equipment. (C)
8. XSE - SE identification — up to 20 alphanumeric characters. (C)

Annex 3

LSC MODEL EQUATIONS

C_1 = Cost of FLU Spares

$$= M\sum_{i=1}^{N}(STK_i)(UC_i) + \sum_{i=1}^{N}\frac{(PFFH)(QPA_i)(UF_i)(1-RIP_i)(NRTS_i)(DRCT_i)}{MTBF_i}(UC_i)$$

$$+\sum_{i=1}^{N}\frac{(TFFH)(QPA_i)(UF_i)(1-RIP_i)(COND_i)}{MTBF_i}(UC_i)$$

The first two terms in C_1 are the cost to fill the base and depot repair pipelines respectively. The quantities computed are those required to support the peak level of program activity. The third term is the cost to replace failed FLUs which will be condemned at base level over the life of the system.

In the first term, STK_i represents the number of spares of the i^{th} FLU required for each base to fill the base repair pipeline including a safety stock to protect against random fluctuations in demand. The computation of STK_i considers the mean demand rate per base,

$$\lambda_i = \frac{(PFFH)(QPA_i)(UF_i)(1-RIP_i)}{(M)(MTBF_i)} \qquad (1.1)$$

the weighted pipeline time

$$t_i = (RTS_i)(BRCT_i) + (NRTS_i)[(OSTCON)(1-OS) + (OSTOS)(OS)] \qquad (1.2)$$

and EBO, the established standard for expected backorders for the weapon system. Therefore, the product, $\lambda_i t_i$, represents the expected number of demands on supply for the i^{th} FLU over its average base repair pipeline time. Then, find the minimum value of STK_i such that

$$\sum_{x > STK_i}(x - STK_i)p(x|\lambda_i t_i) \leq EBO \qquad (1.3)$$

where the distribution of probabilities of demand given a mean demand,

$$p(x \mid \lambda_i t_i) \tag{1.4}$$

is Poisson. Therefore, the cost to provide base repair pipeline spares of the i^{th} FLU for all bases is

$$(M)(STK_i)(UC_i) \tag{1.5}$$

C_2 = On-Equipment Maintenance

$$= \sum_{i=1}^{N} \frac{(TFFH)(QPA_i)(UF_i)}{MTBF_i} [PAMH_i + (RIP_i)(IMH_i) + (1-RIP_i)(RMH_i)] (BLR)$$

$$+ \frac{TFFH}{SMI} (SMH)(BLR) + \boxed{\frac{(TFFH)(EPA)}{CMRI} (ERMH)(BLR)}$$

The first term in C_2 is the labor manhour cost to perform on-equipment (flight line) maintenance on FLUs due to (unscheduled) failures over the life of the system. The element,

$$PAMH_i + (RIP_i)(IMH_i) + (1-RIP_i)(RMH_i) \qquad (2.1)$$

is the weighted average on-equipment maintenance manhours per failure of the i^{th} FLU including Preparation and Access time and either in-place repair or removal and replacement as appropriate.

The second term is the labor manhour cost to perform scheduled maintenance on the complete system over the life cycle.

The third term is applicable only when dealing with a propulsion or powerplant system. It is the maintenance manhour cost to remove and replace whole engines on the aircraft.

C_3 = Off-Equipment Maintenance

$$= \sum_{i=1}^{N} \frac{(TFFH)(QPA_i)(UF_i)(1-RIP_i)}{MTBF_i} \Big\{ (BCMH_i)(BLR) + RTS_i[(BMH_i)(BLR + BMR)$$

$$+ (BMC_i)(UC_i)] + NRTS_i[(DMH_i)(DLR + DMR) + (DMC_i)(UC_i)]$$

$$+ [2(NRTS_i) + COND_i][(PSC)(1-OS) + (PSO)(OS)](1.35\ W_i) \Big\}$$

$$+ \frac{(TFFH)(EPA)(1-ERTS)}{CMRI} (EOH)(EUC)$$

The first term in C_3 is the labor manhour and material cost to perform off-equipment maintenance on failed, removed FLUs in base or depot repair facilities. All failed FLUs are first bench-checked to verify failure and then either repaired in the base intermediate maintenance shop (RTS), returned to the depot for repair (NRTS) or condemned (COND). The cost of failure verification results from expending manhours (BCMH). The cost to repair an item results from direct repair manhours (BMH or DMH) and the implied repair disposition cost to stock and repair lower indenture components and assemblies (BMC or DMC). Included is the transportation cost for NRTS FLUs and condemnation replacements. The 1.35 factor is the ratio of packed to unpacked weight. The second term is applicable only when dealing with a propulsion or powerplant system. It is the implied cost to perform overhaul of a complete engine at the depot including labor and material consumption. It does not include, however, repair and stockage of engine components considered elsewhere as FLUs.

C_4 = Inventory Management Cost

$$= [IMC + (PIUP)(RMC)]\sum_{i=1}^{N}(PA_i + PP_i + 1)$$

$$+ (M)(SA)(PIUP)\sum_{i=1}^{N}(PA_i + PP_i + SP_i + 1)$$

The first term in C_4 is the cost to enter new line items of supply into the government inventory and to manage them over the life of the system.

The second term is the life cycle base level supply management cost of these new items of supply as well as common, already-stock-numbered items which will be carried for the first time in base supply where this system is deployed.

C_5 = Cost of Support Equipment

$$= \sum_{i=1}^{N} \frac{(PFFH)(QPA_i)(UF_i)(1-RIP_i)}{MTBF_i} \sum_{j=1}^{K} \left\{ \frac{(RTS_i)(BMH_i + BCMH_i)}{(BUR_j)(BAA)(1-DOWN_j)}[1 + (PIUP)(COB_j)]CAB_j \right.$$

$$\left. + \frac{(NRTS_i)(DMH_i)}{(DUR_j)(DAA)(1-DOWN_j)}[1 + (PIUP)(COD_j)]CAD_j \right\}$$

$$+ \quad [1 + 0.1(PIUP)][DCA + DPA + M(BCA + BPA + FLA)] \quad + \quad CS \quad + \quad IH$$

The first term in C_5 computes the quantities and costs to acquire and maintain new, peculiar items of depot and base shop support equipment (SE) utilized in repair of FLUs. The quantities are derived by considering the anticipated repair workload, the servicing capability of the shops and certain characteristics of the SE.

From queuing theory, we are given

$$\rho = \frac{\lambda}{n\mu} \quad 1 \tag{5.1}$$

where λ is the workload arrival rate, μ is the service rate of one server, n is the number of servers and ρ is the combined utilization rate of the servers which must be not greater than unity. Our objective is to calculate the minimum number of pieces of each item of support equipment ("servers") necessary to support the anticipated workload. Therefore, we must rearrange terms in (5.1):

$$n = \frac{\lambda}{\rho\mu} \tag{5.2}$$

For our purposes, the arrival rate of workload in the base shop for the i^{th} FLU is given by

$$\lambda = \frac{(PFFH)(QPA_i)(UF_i)(1-RIP_i)(RTS_i)}{MTBF_i} \tag{5.3}$$

The service rate for one unit of the j^{th} item of SE in support of the i^{th} FLU given by

$$\mu = \frac{(BAA)(1-DOWN_j)}{(BMH_i + BCMH_i)} \tag{5.4}$$

And the combined utilization rate, ρ, is given by the variable BUR. Therefore, by combining terms, the quantity

$$\frac{(PFFH)(QPA_i)(UF_i)(1-RIP_i)(RTS_i)(BMH_i + BCMH_i)}{(MTBF_i)(BUR_j)(BAA)(1-DOWN_j)} \tag{5.5}$$

represents the fractional requirement for the j^{th} item of SE to support the i^{th} FLU. In order to compute SE costs realistically, integer quantities should be considered. All fractional requirements for SE item j should be accumulated for all FLUs in the weapon system and the result rounded up to a whole number divisible by M to give the total base-level requirement for SE item j.

A similar discussion applies to the computation of depot SE. Using (5.2) again, the depot parameters are

$$\lambda = \frac{(PFFH)(QPA_i)(UF_i)(1-RIP_i)(NRTS_i)}{MTBF_i} \tag{5.6}$$

$$\mu = \frac{(DAA)(1-DOWN_j)}{DMH_i} \tag{5.7}$$

$$\rho = DUR \tag{5.8}$$

The fractional requirement for the j^{th} item of SE to support the i^{th} FLU is represented by

$$\frac{(PFFH)(QPA_i)(UF_i)(1-RIP_i)(NRTS_i)(DMH_i)}{(MTBF_i)(DUR_j)(DAA)(1-DOWN_j)} \tag{5.9}$$

which should be integerized to give the depot-level requirement for SE item j.

The second term in C_5 is cost to acquire and maintain items of peculiar SE which are not directly workload-related and items of common SE which must be procured in additional quantities. The arbitrary value of 0.1 is the analog of COB or COD used in the first term.

C_6 = Cost of Personnel Training

$$= \frac{[1 + (PIUP)(TRB)]\ TCB}{(PIUP)(PMB)} \left[\sum_{i=1}^{N} \frac{(TFFH)(QPA_i)(UF_i)}{MTBF_i} \left\{ PAMH_i + (RIP_i)(IMH_i) \right.\right.$$

$$\left.\left. + (1-RIP_i)[RMH_i + BCMH_i + (RTS_i)(BMH_i)] \right\} + \frac{TFFH}{SMI}(SMH) \right.$$

$$\left. + \boxed{\frac{(TFFH)(EPA)}{CMRI}(ERMH)} \right]$$

$$+ \frac{[1 + (PIUP-1)(TRD)]\ TCD}{(PIUP)(PMD)} \sum_{i=1}^{N} \frac{(TFFH)(QPA_i)(UF_i)}{MTBF_i} (1-RIP_i)(NRTS_i)(DMH_i)$$

$$+ TE$$

The first and second terms in C_6 are the costs to train maintenance personnel for bases and the depot respectively. Using the second term to simplify the explanation, the quantity

$$\frac{(TFFH)(QPA_i)(UF_i)(1-RIP_i)(NRTS_i)(DMH_i)}{MTBF_i} \tag{6.1}$$

gives the total depot labor manhour requirement for the i^{th} over the life of the system. Dividing (6.1) by the quantity

$$(PIUP)(PMD) \tag{6.2}$$

gives the workload-related personnel equivalents required at the depot to support the i^{th} FLU. Multiplying by the quantity

$$1 + (PIUP-1)(TRD) \tag{6.3}$$

reflects the turnover of personnel and essentially gives the total training requirement over the life of the system which is then multiplied by the cost to train one man, TCD. A similar exercise applies to the computation of base-level training requirements in the first term. Note that the last quantity within the first term is applicable only when dealing with a propulsion system.

C_7 = Cost of Management and Technical Data

$$= \sum_{i=1}^{N} \frac{(TFFH)(QPA_i)(UF_i)}{MTBF_i} [MRO + (1-RIP_i)(MRF + SR + TR)] BLR$$

$$+ \frac{TFFH}{SMI} [MRO + 0.1(SR + TR)] BLR \quad + \quad TD(JJ + H)$$

The first term in C_7 is the maintenance labor cost associated with equipment failures to complete the required on- and off-equipment maintenance forms, supply transaction records and transportation forms. The second term is the similar cost associated with scheduled or periodic maintenance. The third term is the cost to acquire Technical Orders, overhaul manuals, and other special technical documentation or repair instructions.

C_8 = Cost of Facilities

$= FD + (M)(FB)$

This equation gives the cost of new, special base and depot real facilities (including utilities) necessary for operation and maintenance of the system.

C_9 = Cost of Fuel Consumption

$= (TFFH)(EPA)(FR)(FC)$

This equation gives the life cycle fuel cost for those weapon systems having propulsion systems.

C_{10} = Cost of Spare Engines

= $[(LS)(X) + Y]$ EUC

In C_{10}, X is the number of whole spare engines required to fill the base-level portion of the engine pipeline including both the base repair cycle and the Automatic Resupply and Buildup Time. Y is the number of engines required to fill the depot overhaul cycle. Both X and Y include a safety level stock to protect against pipeline shortages due to abnormal or unpredictable demand conditions. The computation of X considers the mean demand rate,

$$\frac{(PFFH)(EPA)}{(LS)(CMRI)} \tag{10.1}$$

the weighted base pipeline time,

$$(ERTS)(BP) + (1-ERTS)(ARBUT) \tag{10.2}$$

and CONF, the established confidence level factor expressed in terms of off-the-shelf availability. The product of the demand rate and the weighted pipeline time gives the argument (ARGB) of the following equation. The desired value of X is the minimum value such that

$$\sum_{n=0}^{X} \frac{(e^{-ARGB})(ARGB)^n}{n!} \geq CONF \tag{10.3}$$

A similar computation applies for Y where the mean demand rate is

$$\frac{(PFFH)(EPA)}{CMRI} \tag{10.4}$$

and the weighted pipeline time is

$$(1-ERTS)(DP) \tag{10.5}$$

The product of these two terms gives the argument (ARGD) of the following equation. The desired value of Y is the minimum value such that

$$\sum_{n=0}^{Y} \frac{(e^{-ARGD})(ARGD)^n}{n!} \geq CONF \qquad (10.6)$$

Annex 4

VARIABLE DATA INPUT SEQUENCE

LEVEL	SOURCE	VARIABLES
Weapon System	Government	LN* TFFH PFFH PIUP M OS EBO NSYS
	Government	LN OSTCON OSTOS IMC RMC PSC PSO TRB TRD
	Government	LN TD SA MRO MRF SR TR PMB PMD
Propulsion Peculiar	Contractor	LN EPA EUC CMRI ERTS ERMH EOH FR
	Government	LN CONF ARBUT BP DP FC LS
System	Contractor	LN XSYS SYSNOUN
	Contractor	LN BCA DCA BPA DPA FLA CS IH N
	Contractor	LN FB FD H JJ SMH SMI TCB TCD TE
	Government	LN BLR DLR BMR DMR BAA DAA
FLU	Contractor	LN XFLU FLUNOUN
	Contractor	LN QPA UC MTBF UF RIP RTS NRTS COND BMC DMC
	Contractor	LN PAMH IMH RMH BCMH BMH DMH W PA PP SP K
	Government	LN BRCT DRCT
SE	Contractor	LN XSE CAB CAD COB COD BUR DUR DOWN

* LN is the line number in the data file.

Annex 5

EXAMPLE OUTPUTS

```
1001 2750000 29160 10 9 .33 .1 5
1002 .38 .53 40.91 104.20 .52 .98 .33 .15
1003 220 20220 .08 .24 .25 .16 1500 1500
1004 2 293080 800 .5 .75 .09 600
1005 .9 .63 1.37 .73 .35 9
1006 23000 PROPULSION
1007 18500 250000 50000 1000000 9100 82000 38400 10
1008 855000 2430000 975 740 10 15 9500 7000 240000
1009 11.70 12.44 2.28 6.72 200 320
1010 23ABA "MODULE #1"
1011 1 22500 140 1 .2 .6 .3 .1 .15 .15
1012 .5 2.5 2.5 .5 60.5 55 65 3 7 12 4
1013 .33 1.5
1014      AGE1  84200.  84200.  .1 .1 .7  .9  .03
1015      AGE2  17160.  17160.  .1 .1 .8  .95 .04
1016      AGE3  34325.  34325.  .1 .1 .8  .9  .05
1017      AGE5 896000. 896000. .1 .1 .85 .95 .07
1018 23ABB "MODULE #2"
1019 2 6750 2500 1 .4 .8 .15 .08 .25 .25
1020 .5 .5 .5 .5 35 30 14 1 6 9 3
1021 .33 1.5
1022      AGE1  84200.  84200.  .1 .1 .7  .9  .03
1023      AGE3  34325.  34325.  .1 .1 .8  .9  .05
1024      AGE5 896000. 896000. .1 .1 .85 .95 .07
1025 23AB0 "MODULE #3"
1026 2 63100 650 1 .2 .5 .3 .2 .2 .2
1027 .5 3.5 2 .5 40 40 85 4 11 16 2
1028 .5 2
1029      AGE2  17160.  17160.  .1 .1 .8  .95 .04
1030      AGE5 896000. 896000. .1 .1 .85 .95 .07
1031 23ABX "MODULE #4"
1032 1 3810 3000 1 .3 .9 0 .1 .1 .1
1033 .5 .5 .5 .5 20 0 10 1 3 7 2
1034 .33 1.5
1035      AGE2  17160.  17160.  .1 .1 .8  .95 .04
1036      AGE5 896000. 896000. .1 .1 .85 .95 .07
1037 23CA0 "MODULE #5"
1038 2 19500 2000 1 .2 .4 .5 .1 .15 .15
1039 .5 5 1 .5 65 60 25 3 8 13 2
1040 .5 1.5
1041      AGE1  84200.  84200.  .1 .1 .7  .9  .03
1042      AGE3  34325.  34325.  .1 .1 .8  .9  .05
1043      AGE5 896000. 896000. .1 .1 .85 .95 .07
1044 23CBX "MODULE #6"
1045 2 500 73600 1 .2 .75 .05 .2 .4 .4
1046 .5 6.5 3 .5 90 110 5 4 19 13 3
1047 1.2 2.5
1048      AGE3  34325.  34325.  .1 .1 .8  .9  .05
1049      AGE8 111200. 111200. .1 .1 .7  .9  .06
1050      AGE5 896000. 896000. .1 .1 .85 .95 .07
1051 23DDX "MODULE #7"
1052 4 2800 8500 1 .1 .9 .05 .05 .25 .2
```

PROGRAM VARIABLES

TFFN	PFFN	PIUP	M	OS	SRO	NSYS	
27500.0.	29160.	10.	9.	0.33	0.10	6	
OSTCOS	OSTOS	IMC	SMC	PSC	PSO	TRD	TRD
0.36	.53	40.91	104.20	0.52	0.98	0.33	0.15
ID	SA	MRO	MRF	SR	TR	PMB	PMD
220.00	23.20	0.08	0.24	0.25	0.16	1500.	1500.

PROPULSION SYSTEM VARIABLES (PECULIAR)

SPA	SUC	CMRI	ERTS	ERMN	EOM	PR
2.	293000.	800.	0.50	0.75	0.09	600.
COST	ARBUT	BP	DF	FC	LS	
0.90	0.63	1.37	0.73	0.35	9.	

23000 SYSTEM VARIABLES -- PROPULSION
*****

BCA	DCA	BPA	DPA	FLA	CS	IN	N	
18500.	280000.	50000.	1000000.	9100.	82000.	0.	10	
PB	**PD**	**N**	**JJ**	**SMH**	**SMI**	**TCB**	**TCD**	**TR**
855000.	2840000.	975.	760.	10.00	15.	9500.	7000.	240000.
BLB	**DLB**	**BMP**	**DMB**	**BAA**	**DAA**			
11.70	12.44	2.28	6.72	200.	320.			

23ABA FLU VARIABLES -- MODULE #1
*****

OPA	UC	MTBF	UP	RIP	RTS	NRTS	COND	BMC	DMC	
1.	22500.	140.	1.00	0.20	0.60	0.30	0.10	0.15	0.15	
PAMH	**IMH**	**BMH**	**SCMH**	**BMH**	**DMH**	**W**	**PA**	**PP**	**SP**	**K**
0.5	4.57	2.50	0.50	60.50	55.00	65.	3.	7.	12.	4
BRCT	**DRCT**									
0.33	1.50									

SUPPORT EQUIPMENT VARIABLES -- AGE1

CAB	CAD	COB	COD	BUR	DUR	DOWN
84200.	84200.	0.10	0.10	0.70	0.90	0.03

SUPPORT EQUIPMENT VARIABLES -- AGE2

CAB	CAD	COB	COD	BUR	DUR	DOWN
17160.	17160.	0.10	0.10	0.80	0.95	0.04

SUPPORT EQUIPMENT VARIABLES -- AGE3

CAB	CAD	COB	COD	BUR	DUR	DOWN
34325.	34325.	0.10	0.10	0.80	0.90	0.05

SUPPORT EQUIPMENT VARIABLES -- AGE5

CAB	CAD	COB	COD	BUR	DUR	DOWN
896000.	896000.	0.10	0.10	0.85	0.95	0.07

```
SYSTEM ?FORT
old or new-N
ready
*RUN TSSMOD*TESTDATA"10"




TOTAL LSC = $   2.99 BILLION.

DO YOU WANT AN EXPLANATION OF YOUR AVAILABLE OPTIONS?
=YES

OPTION 1 - TOTAL LSC BROKEN OUT BY EQUATION
OPTION 2 - ALL SYSTEMS RANKED ON COST
OPTION 3 - COST BREAKOUT BY EQUATION FOR A PARTICULAR SYSTEM
OPTION 4 - COST RANKING OF FLUS FOR A PARTICULAR SYSTEM
OPTION 5 - COST BREAKOUT BY EQUATION FOR A PARTICULAR FLU
OPTION 6 - DETAILED SUPPORT EQUIPMENT ANALYSIS
OPTION 7 - DETAILED SPARES ANALYSIS
OPTION 8 - MAINTENANCE GENERATIONS ANALYSIS
OPTION 9 - FLU WORK UNIT CODE/NOUN CROSS-REFERENCE
OPTION 10 - STOP PROGRAM

WHICH OPTION?
=1

EQUATION           *1          *2          *3          *4          *5
             552808192.   51651251.  911965696.    1781464.  248152610.

EQUATION           *6          *7          *8          *9         *10
              11429708.    4006989.   12225000. 1155000000.   41313000.
```

WHICH OPTION?
=2

SYSTEM	COST(IN MILLIONS)	FRACTION OF TOTAL LSC
23000	1849.27	0.62
74000	551.41	0.18
72000	345.52	0.12
63000	235.10	0.08

WHICH OPTION?
=3
SYSTEM IDENTIFICATION?
=23000

EQUATION	#1	#2	#3	#4	#5
	138013590.	23492209.	282837164.	571842.	188451010.

EQUATION	#6	#7	#8	#9	#10
	8428094.	1034138.	10125000.	1155000000.	41313000.

WHICH OPTION?
=3
SYSTEM IDENTIFICATION?
=74000

EQUATION	#1	#2	#3	#4	#5
	151507000.	4648097.	372292272.	292920.	20971000.

EQUATION	#6	#7	#8	#9	#10
	289473.	709585.	700000.	0.	0.

WHICH OPTION?
=4
SYSTEM IDENTIFICATION?
=23000
HOW MANY FLUS TO BE INCLUDED IN RANKING?
=5

	FLU	COST	FRACTION OF SYSTEM COST
1	23ABO	114077610.	0.06
2	23ABA	103265135.	0.06
3	23EGH	79104371.	0.04
4	23DEF	18543707.	0.01
5	23CAO	13497076.	0.01

CONTRIBUTION OF TOP 5 FLUS = 17 PER CENT OF TOTAL SYSTEM COST.
SYSTEM COST = $ 1849.27 MILLION.

```
WHICH OPTION?
=5
FLU IDENTIFICATION?
=23AB0

EQUATION        #1            #2            #3            #4
          62581200.       277200.     50586741.        75503.

EQUATION        #5            #6            #7
                0.        497566.        59400.

WHICH OPTION?
=5
FLU IDENTIFICATION?
=23ABA

EQUATION        #1            #2            #3            #4
          39082500.       689464.     61415033.        53726.

EQUATION        #5            #6            #7
                0.       1886519.       137893.

WHICH OPTION?
=6
    COL 1 - SE IDENTIFICATION
    COL 2 - FRACTIONAL SE RQMT-BASE (COMPUTED)
    COL 3 - TOTAL SE RQMT-BASE (INTEGERIZED)
    COL 4 - FRACTIONAL SE RQMT-DEPOT (COMPUTED)
    COL 5 - TOTAL SE RQMT-DEPOT (INTEGERIZED)
```

1	2	3	4	5
AGE1	59.27	63.	13.68	14.
AGE2	60.51	63.	14.13	15.
AGE3	54.54	63.	13.67	14.
AGE5	68.70	72.	17.38	18.
AGE4	0.33	9.	0.01	1.
AGE 6	24.86	27.	5.70	6.
AGE8	20.04	27.	5.16	6.
AGE7	9.09	18.	3.53	4.
AGE13	13.93	18.	8.17	9.
AGE9	4.49	9.	2.80	3.
AGE11	4.12	9.	5.86	6.
AGE12	4.17	9.	6.84	7.
SE NUMBER 14	5.04	9.	0.05	1.
AGE10	1.19	9.	0.08	1.
AGE15	4.08	9.	3.26	4.
AGE16	7.05	9.	7.36	8.
AGE17	1.51	9.	6.25	7.
AGE18	1.90	9.	7.62	8.

WHICH OPTION?
=7

WHOLE ENGINES

ARGBASE = 8.10 X = 12.

ARGDEPOT = 26.61 Y = 33.

FLUS

WUC	DMDMEAN	XBO	STK	DPIPE	TOTCOND
23ABA	5.98	0.08	10.	75.	1572.
23ABB	0.51	0.02	2.	4.	67.
23ABO	2.99	0.05	6.	44.	1354.
23ABX	0.22	0.02	1.	0.	65.
23CAO	1.06	0.03	3.	18.	221.
23CBX	0.06	0.06	0.	1.	12.
23DDX	0.82	0.06	2.	2.	111.
23DEF	2.05	0.08	4.	29.	1201.
23EFO	0.08	0.08	0.	1.	22.
23EGH	6.47	0.06	11.	30.	472.
63GAO	2.36	0.05	5.	15.	308.
63GHH	2.20	0.04	5.	44.	551.
63GHX	2.41	0.05	5.	56.	3521.
63PMD	20.48	0.07	29.	371.	11648.
63PMO	8.80	0.07	14.	0.	5658.
63PMX	13.03	0.10	19.	112.	3521.
72FAA	11.84	0.07	18.	120.	1501.
72FAB	3.02	0.05	6.	9.	0.
72FBN	5.33	0.08	9.	18.	0.
72FBO	3.40	0.09	6.	56.	871.
72FGH	3.09	0.06	6.	7.	413.
74MAA	5.29	0.08	9.	33.	688.
74MAB	4.57	0.07	8.	79.	551.
74MBC	8.91	0.08	14.	215.	397.
74MDX	4.61	0.08	8.	16.	476.
74MXX	7.81	0.05	13.	304.	0.

WHICH OPTION?
=8

WUC	PEAK GENS	PEAK OFF-EQUIP GENS	TOTAL GENS	TOTAL OFF-EQUIP GENS
23ABA	208.29	166.63	19642.86	15714.29
23ABB	23.33	14.00	2200.00	1320.00
23AB0	89.72	71.78	8461.54	6769.23
23ABX	9.72	6.80	916.67	641.67
23CA0	29.16	23.33	2750.00	2200.00
23CBX	0.79	0.63	74.73	59.78
23DDX	25.92	23.33	2444.44	2200.00
23DEF	106.04	63.62	10000.00	6000.00
23EF0	3.24	2.27	305.56	213.89
23EGH	166.63	99.98	15714.29	9428.57
63GA0	68.61	65.18	6470.59	6147.06
63GHH	64.80	58.32	6111.11	5500.00
63GHX	116.64	93.31	11000.00	8800.00
63PMD	686.12	617.51	64705.88	58235.29
63PM0	333.26	299.93	31428.57	28285.71
63PMX	466.56	373.25	44000.00	35200.00
72FAA	353.45	318.11	33333.33	30000.00
72FAB	64.80	61.56	6111.11	5805.56
72FBN	116.64	110.81	11000.00	10450.00
72FB0	97.20	92.34	9166.67	8708.33
72FGH	97.20	87.48	9166.67	8250.00
74MAA	194.40	145.80	18333.33	13750.00
74MAB	129.60	116.64	12222.22	11000.00
74MBC	233.28	209.95	22000.00	19800.00
74MDX	106.04	100.73	10000.00	9500.00
74MXX	153.47	151.94	14473.68	14328.95

WHICH OPTION?
=8

WUC	PEAK GENS	PEAK OFF-EQUIP GENS	TOTAL GENS	TOTAL OFF-EQUIP GENS
74MXX	153.47	151.94	14473.68	14328.95
74MBC	233.28	209.95	22000.00	19800.00
74MDX	106.04	100.73	10000.00	9500.00
23AB0	89.72	71.78	8461.54	6769.23
72FBN	116.64	110.81	11000.00	10450.00
23ABA	208.29	166.63	19642.86	15714.29
63PMD	686.12	617.51	64705.88	58235.29
72FB0	97.20	92.34	9166.67	8708.33
63PMX	466.56	373.25	44000.00	35200.00
23E6H	166.63	99.98	15714.29	9428.57
72FAA	353.45	318.11	33333.33	30000.00
72FAB	64.80	61.56	6111.11	5805.56
636HX	116.64	93.31	11000.00	8800.00
74MAB	129.60	116.64	12222.22	11000.00
72F6H	97.20	87.48	9166.67	8250.00
23DEF	106.04	63.62	10000.00	6000.00
23CA0	29.16	23.33	2750.00	2200.00
74MAA	194.40	145.80	18333.33	13750.00
63PM0	333.26	299.93	31428.57	28285.71
636HH	64.80	58.32	6111.11	5500.00
23AB8	23.33	14.00	2200.00	1320.00
23DDX	25.92	23.33	2444.44	2200.00
23CBX	0.79	0.63	74.73	59.78
636A0	68.61	65.18	6470.59	6147.06
23EF0	3.24	2.27	305.56	213.89
23ABX	9.72	6.80	916.67	641.67

WHICH OPTION?
=9

*MENU
Create off at 11.151

```
WHICH OPTION?
=9

  WUC          NOUN

 23ABA   MODULE *1
 23ABB   MODULE *2
 23ABO   MODULE *3
 23ABX   MODULE *4
 23CAO   MODULE *5
 23CBX   MODULE *6
 23DDX   MODULE *7
 23DEF   MODULE *8
 23EFO   MODULE *9
 23EGH   MODULE *10
 63GAO   FLU 63-1
 63GHH   FLU 63-2
 63GHX   FLU 63-3
 63PMD   FLU 63-4
 63PMO   FLU 63-5
 63PMX   FLU 63-6
 72FAA   FLU 72-1
 72FAB   FLU 72-2
 72FBN   FLU 72-3
 72FBO   FLU 72-4
 72FGH   FLU 72-5
 74MAA   FLU 74-1
 74MAB   FLU 74-2
 74MBC   FLU 74-3
 74MDX   FLU 74-4
 74MXX   FLU 74-5

WHICH OPTION?
=10

*
```

TOTAL LSC = $ 2.99 BILLION.

TOTAL LSC BREAKOUT BY EQUATION

#1	#2	#3	#4	#5	#6	#7	#8	#9	#10
532808192.	516512[illegible]1.	911965406.	1781464.	248152610.	11429700.	4006989.	12225000.	1155000000.	41313000.

SYSTEMS RANKED BY COST

SYSTEM	COST(IN MILLIONS)	PCT OF TOTAL LSC
23000	1449.27	0.62
74000	651.41	0.18
72000	345.52	0.12
63000	235.10	0.08

SYSTEM 23000

SYSTEM COST BREAKOUT BY EQUATION

#1	#2	#3	#4	#5	#6	#7	#8	#9	#10
138013590.	23492209.	202037164.	871842.	188451010.	8428098.	10384180.	10125000.	1150000000.	46313000.

COMPONENT PLUS RANKED ON TOTAL COST - - - - - - - - COST BROKEN OUT BY EQUATION

	FLU	COST	FRACTION OF SYSTEM COST	#1	#2	#3	#8	#9	#6	#7
1	23ABO	114077610.	0.06	62581200.	277200.	50586781.	75503.	0.	497586.	59400.
2	23ABA	103265135.	0.06	39082500.	889464.	61415033.	53726.	0.	1086519.	137893.
3	23EGH	79104371.	0.04	19051700.	551571.	58906468.	70088.	0.	438130.	86413.
4	23DEF	18543707.	0.01	10634400.	315900.	7294819.	25413.	0.	218185.	54990.
5	23CAO	13497076.	0.01	5187000.	74003.	7923455.	58445.	0.	234869.	19305.
6	23ABB	3545016.	0.00	600750.	25740.	2760224.	39569.	0.	106635.	12098.
7	23DDX	2784737.	0.00	366800.	30030.	2196128.	36668.	0.	136091.	19019.
8	23CBX	2466574.	0.00	6500.	3672.	72710.	147796.	2228000.	11371.	525.
9	23EFO	916569.	0.00	220800.	3575.	648877.	37403.	0.	4001.	1913.
0	23ADX	743618.	0.00	281840.	10725.	385832.	27231.	0.	32152.	5738.
	TOTALS	338944416.	0.18							

TOTAL SYSTEM COST = 1848266068.

SYSTEM-LEVEL COST = 1510321648.

MAINTENANCE GENERATIONS AND SPARES ANALYSIS

WHOLE ENGINES

ARRBASE = 8.10 A = 12.

ARRDEPOT = 26.61 T = 33.

WUC	PEAK GENS	PEAK OFF-EQUIP GENS	TOTAL GENS	PLUS TOTAL OFF-EQUIP GENS	DMDMEAN	XBO	STK	OPIPE	ECOND
23ADA	208.25	155.61	19642.86	15714.29	5.98	0.08	10.	75.	1572.
23ADB	23.33	14.00	2200.00	1320.00	0.51	0.02	2.	4.	47.
23ADO	89.72	71.78	8461.54	6769.23	2.99	0.05	8.	44.	1354.
23ADX	9.72	6.80	916.67	641.67	0.22	0.02	1.	0.	65.
23CAO	29.16	23.33	2750.00	2200.00	1.06	0.03	3.	18.	221.
23CDX	0.79	0.63	74.73	59.78	0.06	0.06	0.	1.	12.
23DDX	25.92	23.33	2444.44	2200.00	0.82	0.06	2.	2.	111.
23DEF	106.04	63.62	10000.00	6000.00	2.05	0.08	4.	29.	1201.
23EFO	3.24	2.27	305.56	213.89	0.08	0.08	0.	1.	22.
23EGN	166.63	99.98	15714.29	9428.57	6.47	0.06	11.	30.	472.
63GAO	68.61	65.18	6470.59	6147.06	2.36	0.05	5.	15.	308.
63GNN	64.83	58.32	6111.11	5500.00	2.20	0.04	5.	44.	551.
63GNX	116.64	93.31	11000.00	8800.00	2.41	0.05	5.	56.	3521.
63PMD	686.12	617.51	64705.88	58235.29	20.48	0.07	29.	371.	11648.
63PMO	333.26	299.93	31428.57	28285.71	8.80	0.07	14.	0.	5658.
63PMX	466.55	373.25	44000.00	35200.00	13.03	0.10	19.	112.	3521.
72PAA	353.45	318.11	33333.33	30000.00	11.84	0.07	18.	120.	1501.
72PAB	64.83	61.54	6111.11	5805.56	3.02	0.05	6.	9.	0.
72PBN	116.64	110.81	11000.00	10450.00	5.33	0.08	9.	18.	0.
72PBO	97.20	92.34	9166.67	8708.33	3.40	0.09	6.	56.	871.
72PGN	97.20	87.48	9166.67	8250.00	3.09	0.06	6.	7.	413.
74MAA	194.40	145.80	18333.33	13750.00	5.29	0.08	9.	33.	688.
74MAB	129.60	116.64	12222.22	11000.00	4.57	0.07	8.	79.	551.
74MBC	233.28	209.95	22000.00	19800.00	8.91	0.08	14.	215.	397.
74MDX	106.04	100.73	10000.00	9500.00	4.61	0.08	8.	18.	476.
74MXX	153.47	151.94	14473.68	14328.95	7.81	0.05	13.	304.	0.

SE ANALYSIS

IDENTIFICATION	FRACTIONAL BASE SE REQUIREMENT (COMPUTED)	TOTAL BASE SE REQUIREMENT (INTEGERIZED)	FRACTIONAL DEPOT SE REQUIREMENT (COMPUTED)	TOTAL DEPOT SE REQUIREMENT (INTEGERIZED)
A3E1	59.27	63.	13.68	14.
A3E2	60.51	63.	14.13	15.
A3E3	56.94	63.	13.67	14.
A3E5	68.70	72.	17.38	18.
A3E4	0.33	9.	0.01	1.
A3E 6	24.86	27.	5.70	6.
A3E8	20.04	27.	5.16	6.
A3E7	9.09	18.	3.53	4.
A3E13	13.93	18.	8.17	9.
A3E9	4.49	9.	2.80	3.
A3E11	4.12	9.	5.86	6.
A3E12	4.17	9.	6.84	7.
SE NUMBER 14	5.04	9.	0.05	1.
A3E10	1.19	9.	0.08	1.
A3E15	4.08	9.	3.26	4.
A3E16	7.05	9.	7.36	8.
A3E17	1.51	9.	6.25	7.
A3E18	1.90	9.	7.62	8.

Annex 6

PROGRAM LISTING FOR BATCHMOD

```
F204T.01  06-10-75    11.860
$       IDENT    WP0819,AQM   WEAVER      AQM/BATCHMOD
$       FORTY    NDECK
$       LIMITS   ,30K
************* AQM/BATCHMOD *************
****************************************
        DIMENSION FLUMAT(500,8),SEMAT(500,9),SYSMAT(30,13),SECUM(50,5)
        DIMENSION EOTOT(10)
        CHARACTER XSYS*5(30),XFLU*5(500,2),XSE*20(500),SEFLU*5(500,2)
        CHARACTER SYSNOUN*60(30),FLUNOUN*60(500),XSECUM*20(50)
        DATA SYSMAT,FLUMAT,EOTOT/4400*0./
        REAL M,IMC,IMH,JJ,LS,M,MRF,MRO,MTBF,NRTS
        TOTLSC=0.

****************************************************
*********** READ WEAPON SYSTEM VARIABLES ***********
****************************************************

        READ(5,2) TFFH,PFFH,PIUP,M,OS,EBO,NSYS
        READ(5,2) OSTCON,OSTOS,IMC,RMC,PSC,PSD,TRB,TRD
        READ(5,2) TD,SA,MRO,MRF,SR,TR,PMB,PMD
    2   FORMAT(V)
        IF(NSYS.LE.30) GO TO 4
        PRINT 3
    3   FORMAT("SYSMAT ARRAY MUST BE REDIMENSIONED")
        STOP
    4   CONTINUE
        PRINT 10
   10   FORMAT(/////36X,"MAINTENANCE GENERATIONS AND SPARES ANALYSIS")

***********************************************************
************** READ PROPULSION SYSTEM VARIABLES ***********
***********************************************************

        READ(5,2) EPA,EUC,CHRT,ERTS,ERMH,EOH,ER
        READ(5,2) CONF,ARBUT,BP,DP,FC,LS

***************************************************************
*********** COMPUTE BASE ENGINE SPARES STOCK LEVEL ************
***************************************************************

        ARGBASE=EPA*PFFH*(ERTS*BP+(1.-ERTS)*ARBUT)/(CHRT*LS)
        X=ENGCOMP(ARGBASE,CONF)
        ARGDEPOT=EPA*PFFH*(1.-ERTS)*DP/CHRT
        Y=ENGCOMP(ARGDEPOT,CONF)
        PRINT 26,ARGBASE,X,ARGDEPOT,Y
   26   FORMAT(/////51X,"WHOLE ENGINES"//44X,"ARGBASE =",F6.2,7X,"X =",
       *F5.0//43X,"ARGDEPOT =",F6.2,7X,"Y =",F5.0)

   30   INEXT=1
        JNEXT=1
        PRINT 32
   32   FORMAT(/////56X,"PLUS"//31X,"PEAK",22X,"TOTAL"/20X,"PEAK",5X,
       *"OFF-EQUIP",6X,"TOTAL",6X,"OFF-EQUIP"/10X,"NUC",7X,"GENS",
       *7X,"GENS",10X,"GENS",9X,"GENS",8X,"DMDMEAN",8X,"XBO",8X,"STK",
       *7X,"DPIPE",8X,"TCOND"//)
```

```
********************************************
************** READ SYSTEM VARIABLES ***********
********************************************
      DO 1000 IS=1,NSYS
      READ(5,2) XSYS(IS),SYSNOUN(IS)
      READ(5,2) BCA,DCA,BPA,DPA,FLA,CS,IN,N
      READ(5,2) FB,FD,M,JJ,SMH,SMI,TCB,TCD,TE
      READ(5,2) BLR,DLR,SMR,DMR,BAA,DAA
      SYSMAT(IS,2)=TFFH*SMH*BLR/SMI
      SYSMAT(IS,5)=(1+0.1*PIUP)*(DCA+DPA+M*(BCA+BPA+FLA))+CS+IN
      C6X=TCB*(1.+(PIUP-1.)*TRB)/(PIUP*PMB)
      C6Y=TCD*(1.+(PIUP-1.)*TRD)/(PIUP*PMD)
      SYSMAT(IS,6)=C6X*TFFH*SMR/SMI + TE
      SYSMAT(IS,7)=TFFH*BLR*(MRO+0.1*(SR+TR))/SMI+TD*(JJ+K)
      SYSMAT(IS,8)=M*FB+FD
      IF(XSYS(IS).NE."23000") GO TO 34
      SYSMAT(IS,2)=SYSMAT(IS,2)+TFFH*EPA*ERMH*BLR/CKRI
      SYSMAT(IS,3)=TFFH*EPA*(1.-ERTS)*EOH*EUC/CMRI
      SYSMAT(IS,6)=SYSMAT(IS,6)+C6X*TFFH*EPA*ERMH/CMRI
      SYSMAT(1,9)=TFFH*EPA*FR*FC
      SYSMAT(1,10)=(X*LS + Y)*EUC
   34 IF(N.EQ.0) GO TO 1000

****************************************
*********** READ FLU VARIABLES ***********
****************************************
      IMAX=INEXT+N-1
      IF(IMAX.LE.500) GO TO 38
      PRINT 37
   37 FORMAT("FLUMAT ARRAY MUST BE REDIMENSIONED")
      STOP

   38 DO 999 I=INEXT,IMAX
      READ(5,2) XFLU(I,1),FLUNOUN(I)
      READ(5,2) QPA,UC,MTBF,UF,RIP,RTS,NRTS,COND,BMC,DMC
      READ(5,2) PAMH,IMH,RMH,BCMH,BMH,DMH,W,PA,PP,SP,K
      READ(5,2) BRCT,DRCT
      XFLU(I,2)=XSYS(IS)
      PKGEN=PFFH*QPA*UF/MTBF
      PKOEGEN=PKGEN*(1.-RIP)
      TOTGEN=TFFH*QPA*UF/MTBF
      TOTOEGEN=TOTGEN*(1.-RIP)
      DMDMEAN=PKOEGEN*(BRCT*RTS+NRTS*((1.-OS)*OSTCON+OS*OSTOS))/M

************************************************************
*********** COMPUTE BASE FLU SPARES STOCK LEVEL ***********
************************************************************
      XBO=DMDMEAN
      PROBX=EXP(-DMDMEAN)
      STK=0.
      SUM=0.
```

F2047 01 06-10-75 11.560

```
   41 IF(XBO.LE.EBO) GO TO 45
      SUM=SUM+PROBX
      XBO=XBO+SUM-1.
      STK=STK+1.
      PROBX=PROBX*DMDMEAN/STK
      GO TO 41
   45 CONTINUE

      DPIPE=IFIX(PKOEGEN*NRTS*ORCT + 0.99999999)
      TCOND=IFIX(TOTOEGEN*COND + 0.99999999)

*********************************************
**** PRINT MAINT GENS & SPARES INFO *******
*********************************************

      PRINT 50,XFLU(I,1),PKGEN,PKOEGEN,TOTGEN,TOTOEGEN,DMDMEAN,XBO,
     *STK,DPIPE,TCOND
   50 FORMAT(9X,A5,2F11.2,2X,2F13.2,2F12.2,F11.0,F12.0,F14.0)

      PLUMAT(I,1)=UC*(STK*M+DPIPE+TCOND)
      PLUMAT(I,2)=TOTGEN*(PAMH+RIP*IMH+(1.-RIP)*RMH)*BLR
      PLUMAT(I,3)=TOTOEGEN*(BCMH*BLR+RTS*(BMH*(BLR+BMR)+BMC*UC)+
     *NRTS*(DMH*(DLR+DMR)+DMC*UC)+(2.*NRTS+COND)*((1.-OS)*PSC+
     *OS*PSO)*1.35*W)
      IF(RTS.NE.0.) GO TO 46
      PLUMAT(I,4)=(IMC+PIUP*RMC)*(1.+PA+PP)+M*SA*PIUP
      GO TO 47
   46 PLUMAT(I,4)=(IMC+PIUP*RMC)*(1.+PA+PP)+M*SA*PIUP*(1.+PA+PP+SP)
   47 PLUMAT(I,6)=C6X*TOTGEN*(PAMH+RIP*IMH+(1.-RIP)*(RMH+BCMH+
     *RTS*BMH))+C6Y*TOTOEGEN*NRTS*DMH
      PLUMAT(I,7)=TOTGEN*(MRO+(1.-RIP)*(MRF+BH+TR))*BLR
      IF (K.EQ.0) GO TO 999

***************************************
*********** READ SE VARIABLES **********
***************************************

      JMAX=JNEXT+K-1
      IF(JMAX.LE.500) GO TO 49
      PRINT 48
   48 FORMAT("SEMAT ARRAY MUST BE REDIMENSIONED")
      STOP

   49 DO 998 J=JNEXT,JMAX
      READ(5,2)XSE(J),CAB,CAD,COB,COD,BUR,DUR,DOWN
      SEFLU(J,1)=XFLU(I,1)
      SEFLU(J,2)=XFLU(I,2)
      SEMAT(J,4)=PKOEGEN*RTS*BMH/(BUR*BAA*(1.-DOWN))
      SEMAT(J,5)=PKOEGEN*NRTS*DMH/(DUR*DAA*(1.-DOWN))
      SEMAT(J,6)=CAB
      SEMAT(J,7)=CAD
      SEMAT(J,8)=COB
      SEMAT(J,9)=COD
  998 CONTINUE
```

```
      JNEXT=JNEXT+K
  999 CONTINUE
      INEXT=INEXT+N
 1000 CONTINUE
C
C********************************************
C*********** ESTABLISH SECUM ***********
C********************************************
      IF(J.EQ.0) GO TO 91
      JH=0
      DO 90 JE=1,J
      IF(XSE(JE).EQ."0") GO TO 90
      UFLU=0.
      USYS=0.
      JH=JH+1
      XSECUM(JH)=XSE(JE)
      XSE(JE)="0"
      SECUM(JH,2)=SEMAT(JE,4)
      SECUM(JH,4)=SEMAT(JE,5)
      JH=JE+1
      DO 80 JF=JH,J
      IF(XSE(JF).NE.XSECUM(JH)) GO TO 80
      XSE(JF)="C"
      SECUM(JH,2)=SECUM(JH,2)+SEMAT(JF,4)
      SECUM(JH,4)=SECUM(JH,4)+SEMAT(JF,5)
      UFLU=1.
      IF(SEFLU(JF,2).EQ.SEFLU(JE,2)) GO TO 80
      USYS=1.
   80 CONTINUE
      SEB=SECUM(JH,2)/M
      SECUM(JH,3)=M*IFIX(SEB + 0.999999)
      SECUM(JH,5)=IFIX(SECUM(JH,4) + 0.999999)
      CSP=SECUM(JH,3)*SEMAT(JE,6)*(1.+PICP*SEMAT(JE,8))
      CSQ=SECUM(JH,5)*SEMAT(JE,7)*(1.+PICP*SEMAT(JE,9))
      IF(USYS.EQ.1.) GO TO 89
      IF(UFLU.EQ.1.) GO TO 87
      DO 86 JC=1,I
      IF(XFLU(JC,1).NE.SEFLU(JE,1)) GO TO 86
      FLUMAT(JC,5)=FLUMAT(JC,5)+CSP+CSQ
      GO TO 90
   86 CONTINUE
   87 DO 88 IQ=1,NSYS
      IF(XSYS(IQ).NE.SEFLU(JE,2)) GO TO 88
      SYSMAT(IQ,5)=SYSMAT(IQ,5)+CSP+CSQ
      GO TO 90
   88 CONTINUE
   89 EQTOT(5)=EQTOT(5)+CSP+CSQ
   90 CONTINUE
C
C********************************************
C*********** COMPUTE FLU COST ***********
C********************************************
```

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```
   91 DO 92 IB=1,I
      DO 92 IC=1,7
      FLUMAT(IB,8)=FLUMAT(IB,8)+FLUMAT(IB,IC)
   92 CONTINUE

*****************************************
************** COMPUTE SYSTEM COST **********
*****************************************
      DO 96 IK=1,NSYS
      DO 93 JQ=1,10
      SYSMAT(IK,11)=SYSMAT(IK,11)+SYSMAT(IK,JQ)
   93 CONTINUE
      DO 95 IL=1,I
      IF(XFLU(IL,2).NE.XSYS(IK)) GO TO 95
      DO 94 IM=1,7
      SYSMAT(IK,IM)=SYSMAT(IK,IM)+FLUMAT(IL,IM)
   94 CONTINUE
   95 CONTINUE
   96 CONTINUE
      DO 97 JN=1,NSYS
      DO 97 JP=1,10
      SYSMAT(JN,12)=SYSMAT(JN,12)+SYSMAT(JN,JP)
   97 CONTINUE

*********************************************
********** COMPUTE WEAPON SYSTEM COST **********
*********************************************
      DO 98 MP=1,10
      DO 98 MR=1,NSYS
   98 EQTOT(MP)=EQTOT(MP)+SYSMAT(MR,MP)
      DO 99 IN=1,10
   99 TOTLSC=TOTLSC+EQTOT(IN)

***********************************
*********** PRINT OUTPUT **********
***********************************
      PRINT 105
  105 FORMAT(1H1///23X,"FLU CROSS-REFERENCE"///20X,"WUC",12X,"NOUN"//)
      DO 110 JZ=1,I
  110 PRINT 112,XFLU(JZ,1),FLUNOUN(JZ)
  112 FORMAT(19X,A5,6X,A50)
      IF(TOTLSC.LT.10**6) GO TO 121
      IF(TOTLSC.LT.10**9) GO TO 117
      PRINT 115,TOTLSC/10**9
  115 FORMAT(1H1//////////50X,"TOTAL LSC = $",F7.2," BILLION.")
      GO TO 124
  117 PRINT 119,TOTLSC/10**6
  119 FORMAT(1H1//////////50X,"TOTAL LSC = $",F7.2," MILLION.")
      GO TO 124
  121 PRINT 123,TOTLSC
  123 FORMAT(1H1//////////50X,"TOTAL LSC = $",F7.0)
```

```
  124 PRINT 122,(EQTOT(JX),JX=1,10)
  122 FORMAT(////50X,"TOTAL LSC BREAKOUT BY EQUATION"//9X,"#1",
     *10X,"#2",10X,"#3",10X,"#4",10X,"#5",10X,"#6",10X,"#7",10X,
     *"#8",10X,"#9",10X,"#10"/3X,10F12.0)

      PRINT 125
  125 FORMAT(////54X,"SYSTEMS RANKED BY COST"//,38X,"SYSTEM",
     *6X,"COST(IN MILLIONS)",6X,"PCT OF TOTAL LSC"//)
      CALL SORT(SYSMAT,30,13,12,XSYS,1)
      CALL SORT(FLUMAT,500,8,8,XFLU,2)
      DO 130 IX=1,NSYS
      SYSMAT(IX,13)=SYSMAT(IX,12)/TOTLSC
      TSYSMAT=SYSMAT(IX,12)/10**6
      PRINT 128,XSYS(IX),TSYSMAT,SYSMAT(IX,13)
  128 FORMAT(39X,A5,F18.2,F21.2)
  130 CONTINUE

      DO 400 IE=1,NSYS
      PRINT 200,XSYS(IE)
  200 FORMAT(1H1////50X,"SYSTEM ",A5///40X,"SYSTEM COST ",
     *"BREAKOUT BY EQUATION"//9X,"#1",10X,"#2",10X,"#3",10X,
     *"#4",10X,"#5",10X,"#6",10X,"#7",10X,"#8",10X,
     *"#9",9X,"#10")
      PRINT 210,(SYSMAT(IE,IG),IG=1,10)
  210 FORMAT(3X,10F12.0)
      PRINT 220
  220 FORMAT(///18X,"COMPONENT FLUS RANKED ON TOTAL COST - - - - ",
     *"- - - - COST BROKEN OUT BY EQUATION"//30X,"FRACTION OF"/11X,
     *"FLU",7X,"COST",5X,"SYSTEM COST",9X,"#1",10X,
     *"#2",10X,"#3",10X,"#4",10X,"#5",10X,"#6",10X,"#7"//)
      IR=0
      DO 370 IY=1,I
      IF(XFLU(IY,2).NE.XSYS(IE)) GO TO 370
      IR=IR+1
      PCT=FLUMAT(IY,8)/SYSMAT(IE,12)
      PRINT 360,IR,XFLU(IY,1),FLUMAT(IY,8),PCT,(FLUMAT(IY,IP),IP=1,7)
  360 FORMAT(I5,A10,F12.0,F11.2,5X,7F12.0)
  370 CONTINUE
      TOTL=SYSMAT(IE,12)-SYSMAT(IE,11)
      PTOTL=TOTL/SYSMAT(IE,12)
      PRINT 380,TOTL,PTOTL,SYSMAT(IE,12),SYSMAT(IE,11)
  380 FORMAT(17X,"-------------",7X,"-----"//7X,"TOTALS",F14.0,F11.2///
     *//7X,"TOTAL SYSTEM COST =",F14.0//7X,
     *"SYSTEM-LEVEL COST =",F14.0)
  400 CONTINUE
      IF(J.EQ.0) STOP

      PRINT 500
  500 FORMAT(1H1////52X,"SE ANALYSIS"///23X,"FRACTIONAL BASE SE",
     *10X,"TOTAL BASE SE",10X,"FRACTIONAL DEPOT SE",8X,"TOTAL ",
     *"DEPOT SE"/3X,"IDENTIFICATION",4X,"REQUIREMENT (COMPUTED)",
     *3X,"REQUIREMENT (INTEGERIZED)",3X,"REQUIREMENT (COMPUTED)",
```

```
     *3X,"REQUIREMENT (INTEGERIZED)"//)
      DO 530 JK=1,JK
      PRINT 520,XSECUM(JK),(SECUM(JK,JR),JR=2,5)
  520 FORMAT(3X,A20,F11.2,F25.0,F28.2,F25.0)
  530 CONTINUE
      STOP
      END
****************************************************
********* SUBROUTINE TO SORT GIVEN MATRIX *********
****************************************************
      SUBROUTINE SORT(XMAT,MAXROW,MAXCOL,NCOL,YMAT,ICOL)
      DIMENSION XMAT(MAXROW,MAXCOL)
      CHARACTER YMAT*5(MAXROW,ICOL),CTEMP*5
      IMAX=MAXROW-1
      DO 700 I=1,IMAX
      JFIRST=I+1
      DO 700 J=JFIRST,MAXROW
      IF(XMAT(I,NCOL).GE.XMAT(J,NCOL)) GO TO 700
      DO 690 K=1,MAXCOL
      TEMP=XMAT(I,K)
      XMAT(I,K)=XMAT(J,K)
      XMAT(J,K)=TEMP
  690 CONTINUE
      DO 695 L=1,ICOL
      CTEMP=YMAT(I,L)
      YMAT(I,L)=YMAT(J,L)
      YMAT(J,L)=CTEMP
  695 CONTINUE
  700 CONTINUE
      RETURN
      END
*****************************************************
****** FUNCTION TO COMPUTE SPARE ENGINES ************
*****************************************************
      FUNCTION ENGCOMP(ARG,CONF)
      IF(ARG.GT.85.) GO TO 820
      ENGCOMP=0.
      PROBXX=EXP(-ARG)
      TCONF=PROBXX
  810 IF(TCONF.GE.CONF) RETURN
      ENGCOMP=ENGCOMP+1.
      PROBXX=PROBXX*ARG/ENGCOMP
      TCONF=TCONF+PROBXX
      GO TO 810
  820 ENGCOMP=IFIX(ARG + 1.28*SQRT(ARG) + 0.999999)
      PRINT 821
  821 FORMAT("WARNING -- CONF IS NOT EQUAL TO 0.90"/
     *"COEFFICIENT IN FUNCTION SIKF MUST BE CHANGED")
      RETURN
      END
$     OPTION  FORTRAN,NOMAP
$     EXECUTE
```

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$ LIMITS ,30K

Appendix F

WORK BREAKDOWN STRUCTURE

Table F-1 lists the first four levels of indenture of the Work Breakdown Structure (WBS) of the Countermeasures Set for the AN/ALQ-XXX. The WBS numbers correspond to the numbers in the blocks of Figure III-2 contained in the text.

Table F-1. Countermeasures Set, AN/ALQ-XXX, Work Breakdown Structure [Reference: MIL-STD-881A]

LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	LEVEL 5
AN/ALQ-XXX DEVELOPMENT PROGRAM 1A00000	DESIGN AND DEVELOPMENT 2A10000	Broadband Antenna 3A11000	TYPICAL: Design 4A11100	See design flow charts for more detail
			Analyses 4A11200	
			Breadboard 4A11300	
			Document 4A11400	
			Design Review 4A11500	
			Methodize 4A11600	
			Fabricate 4A11700	
			Test Development 4A11800	
			Test Acceptance 4A11900	
		Log-Video Amplifier/Detector 3A12000		
		Amplitude Comparison DF 3A13000		
		Pulse Encoder 3A14000		
		Signal Processor 3A15000		
		RWR Antenna 3A16000		
		Wide-Band Superhet 3A17000		

(Continued)

Table F-1. Countermeasures Set, AN/ALQ-XXX, Work Breakdown Structure (Cont'd-2)

LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	LEVEL 5
AN/ALQ-XXX DEVELOPMENT PROGRAM 1A00000	DESIGN AND DEVELOPMENT 2A10000	Digital RF Memory 3A18000 Techniques Generator 3A19000 TWT Transmitter 3A1A000 Transmit Antenna (Fore) 3A1B000 Transmit Antenna (Aft) 3A1C000 Broadband Antenna (Fore) 3A1D000 Broadband Antenna (Aft) 3A1E000 Compressive Receiver 3A1F000 Jamming Transmitter 3A1G000 Comm Transmit Antenna (Fore) 3A1H000 Comm Transmit Antenna (Aft) 3A11000 MWR Antenna 3A1J000 MWR Transmitter 3A1K000	See above	See design flow chart for more detail

(Continued)

Table F-1. Countermeasures Set, AN/ALQ-XXX, Work Breakdown Structure (Cont'd-3)

LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	LEVEL 5
AN/ALQ-XXX DEVELOPMENT PROGRAM 1A00000	DESIGN AND DEVELOPMENT 2A10000	Narrowband Receiver 3A1L000	See above	See design flow chart for more detail
		Doppler Filter 3A1M000		
	SOFTWARE DESIGN AND DEVELOPMENT 2A20000	Operational Software 3A21000	TYPICAL: Program Performance Requirement 4A21100	
			Schema Development 4A21200	
			Flow Charting 4A21300	
			Program Reviews 4A21400	
			Coding 4A21500	
			Module Testing/ Integration 4A21600	
			Program Performance Tests 4A21700	
		Support Software 3A22000		
		Software Facilities 3A23000		
	SYSTEM TEST AND EVALUATION 2A30000	System Integration 3A31000	TYPICAL: Each system serial number has a separate Level 4 4A31100 through 4A31n00	

(Continued)

Table F-1. Countermeasures Set, AN/ALQ-XXX, Work Breakdown Structure (Cont'd-4)

LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	LEVEL 5
AN/ALQ-XXX DEVELOPMENT PROGRAM 1A00000	SYSTEM TEST AND EVALUATION 2A30000	System Software Validation and Verification 3A32000	TYPICAL: Operational Software 4A32100	See design flow chart for more detail
			Support Software 4A32200	
			Software Facilities 4A32300	
		Reliability Development Tests 3A33000	TYPICAL: Each LRU is tested separately 4A33100 through 4A33n00	
		Qualification Tests 3A3400	TYPICAL: Each LRU is tested separately 4A34100 through 4A34n00	
		Maintainability Demonstration 3A3500	TYPICAL: Each LRU is tested separately 4A33100 through 4A33n00	
		BIT Tests 3A3600	TYPICAL: Each LRU is tested separately 4A36100 through 4A36n00 and the system is tested as a whole 4A36(n+1)00	
		Test Facilities 3A37000	TYPICAL: Each Test Facility is accounted for 4A37100 through 4A37n00	
	AN/ALQ-XXX REWORK 2A40000	Malfunction Analyses and Reports 3A41000		

(Continued)

Table F-1. Countermeasures Set, AN/ALQ-XXX, Work Breakdown Structure (Cont'd-5)

LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	LEVEL 5
AN/ALQ-XXX DEVELOPMENT PROGRAM 1A00000	AN/ALQ-XXX REWORK 2A4000	Rework Orders 3A42000		See design flow chart for more detail
		Change Orders 3A43000		
			TYPICAL: Design Changes 4A43100	
			Document 4A43200	
			Review 4A43300	
			Methodize 4A43400	
			Fabricate 4A43500	
			Repeat Tests 4A43600	
		Review Board 3A44000		
	INTEGRATED LOGISTIC SUPPORT 2A50000	ILS Management 3A51000	Reliability Management 4A51100	
			Maintainability and Maintenance Management 4A51200	
			Support Equipment Management 4A51300	
			Supply Support Management 4A51400	

(Continued)

Table F-1. Countermeasures Set, AN/ALQ-XXX, Work Breakdown Structure (Cont'd-6)

LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	LEVEL 5
AN/ALQ-XXX DEVELOPMENT PROGRAM 1A00000	INTEGRATED LOGISTIC SUPPORT 2A50000	ILS Management 3A51000	TYPICAL: Packaging, Handling, and Transportation Management 4A51500	See design flow chart for more detail
			Technical Data Management 4A51600	
			Facilities Site/ Unit Activation Management 4A51700	
			Personnel and Training, Pre-operational Support Management 4A51800	
		Logistic Support Analysis (LSA) 3A52000	Support-Related Design Inputs (Task 205 MIL-STD-1388-1A) 4A52100	
			Reliability Activities 4A52200	
			Maintainability Activities 4A52300	
			LCC/LOR Activities 4A52400	
			Support Equipment Planning 4A52500	

(Continued)

Table F-1. Countermeasures Set, AN/ALQ-XXX, Work Breakdown Structure (Cont'd-7)

LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	LEVEL 5
AN/ALQ-XXX DEVELOPMENT PROGRAM 1A00000	INTEGRATED LOGISTIC SUPPORT 2A50000	Logistic Support Analysis (LSA) 3A52000	TYPICAL: Spares Planning 4A52600	See design flow chart for more detail
			PHT Activities 4A52700	
			Technical Data Planning 4A52800	
			Facilities Planning 4A52900	
			Personnel, Training and Preoperational Support Planning 4A52A00	
			Contractor Support Planning 4A52B00	
			Preparation and Evaluation of Alternatives 4A52C00	
			Malfunction Reporting 4A52D00	
			LSA Support for Engineering Change Proposals 4A52E00	
		Sales Representatives 3A61000		
	MANAGEMENT 2A60000	Project Management 3A62000	Financial Management 4A62100	

(Continued)

Table F-1. Countermeasures Set, AN/ALQ-XXX, Work Breakdown Structure (Cont'd-8)

LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	LEVEL 5
AN/ALQ-XXX DEVELOPMENT PROGRAM 1A00000	MANAGEMENT 2A60000	Project Management 3A62000	TYPICAL: Functional Management 4A62200	See design flow chart for more detail
		Engineering Management 3A63000	Systems Engineering Management 4A63100	
			"Ilities" Engineering Management (usually a matrix management structure) 4A63200	
			Manufacturing Management 4A63300	
			Test Engineering Management 4A63400	
			Repair Facility Management 4A63500	
	DATA 2A70000	Management Data 3A71000	Financial Data 4A71100	
			Design Audit Data 4A71200	
			Program Plans 4A71300	
		Engineering Data 3A72000	Design Specifications 4A72100	
			Purchase Specifications 4A72200	

(Continued)

Table F-1. Countermeasures Set, AN/ALQ-XXX, Work Breakdown Structure (Cont'd-9)

LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	LEVEL 5
AN/ALQ-XXX DEVELOPMENT PROGRAM 1A00000	DATA 2A70000	Engineering Data 3A72000	TYPICAL: Design Release/ Review Data Packages 4A72300	See design flow chart for more detail
			Parts Lists 4A72400	
			Drawings 4A72500	
			Risk Analyses 4A72600	
			Performance Analyses Reports 4A72700	
			Environmental Analyses Reports 4A72800	
			Design Status Reports 4A72900	
		Software Data 3A73000	Software Specifications 4A73100	
			Design Documents 4A73200	
			Planning Documents 4A73300	
			Validation/ Certification Reports 4A73400	
		ILS Data 3A74000	ILS Plan 4A74100	

(Continued)

Table F-1. Countermeasures Set, AN/ALQ-XXX, Work Breakdown Structure (Cont'd-10)

LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	LEVEL 5
AN/ALQ-XXX DEVELOPMENT PROGRAM 1A00000	DATA 2A70000	ILS Data 3A74000	TYPICAL: LSAR 4A74200	See design flow chart for more detail
			"Ilities" Analyses Reports 4A74300	
			Technical Publications 4A74400	
			Test Documentation 4A74500	
			Support Equipment Documentation 4A74600	
			Other Documentation (see separate list) 4A74700 through 4A74n00	
	INDUSTRIAL FACILITIES 2A80000	Manufacturing Facilities 3A81000	Machines 4A81100	
			Machine Tools 4A81200	
			Floor Space 4A81300	
			Assembly Facilities 4A81400	
			Stock Room 4A81400	
			GFE 4A81500	

(Continued)

Table F-1. Countermeasures Set, AN/ALQ-XXX, Work Breakdown Structure (Cont'd-11)

LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	LEVEL 5
AN/ALQ-XXX DEVELOPMENT PROGRAM 1A00000	INDUSTRIAL FACILITIES 2A80000	Manufacturing Facilities 3A81000	TYPICAL: Safeguards 4A81500	See design flow chart for more detail
		New Construction/ Conversion 3A82000	Design 4A82100	
			Test/Certification 4A82200	
			Security	
	INITIAL SPARES/ REPAIR PARTS 2A90000	Planning and Pricing 3A91000		
		Manufacture 3A92000		
		Test and Ship 3A93000		
	PROCUREMENT SUBCONTRACTS PARTS ACQUISITION 2AA0000	Planning and Pricing 3AA1000		
		Procurement Specifications 3AA20000		
		RFPs 3AA30000	Negotiation 4AA3100	
			Purchase Orders 4AA3200	
			QA Requirements 4AA3300	

(Concluded)

Appendix G

SUPPORTABILITY DATA TYPES, SOURCES, AND APPLICATION

Table G-1 details the data requirements, their form, and their sources and destinations.

Table G-1. Key to Supportability Data Types, Sources, and Application

NAME	TYPE OF DATA	REMARKS
1. DESIGN GUIDANCE		
a. Maintenance Concept	Text	From human interpretation of requirements and design rule preparation by the Maintainability Engineer.
b. Supportability Specification	Text	From human interpretation of requirements and design rule preparation by the Maintainability Engineer.
c. Target Support Costs	Text	From the government acquisition team for human interpretation, design rule preparation, and input to trade studies (e.g., Item 5).
d. Performance Requirements	Text	From the specification for human interpretation and design rule preparation.
e. Comparison System	Digital Data Fields	These fields would be obtained from the LSAR (MIL-STD-1388) of a predecessor system as obtained from a data dump, which could be either batch or interactive. The data would follow the precise format specified for the A, B, and C sheets of the LSAR (e.g., a record number, usually the Logistics Control Number (LCN), a card number, a field number within that card, and a numeric representing the data in the field). Depending on the sophistication of the workstation this data may: 1. Be interpreted by a government specialist for application in Item 2 and modifying the design guidance that may be derived from a design data base. 2. Be a process that could automatically do data base searches and allocations based on these data.
f. Lessons Learned Feedback	Text	From human interpretation of field data, Lessons Learned Repository, and comparison system malfunction reports.
	Information Resident in Data Base Management System	This is one of the objectives of ULCE. A random access data base would permit searching and visual display on a screen of lessons learned that pertain to the particular design or facet of design in the CAE workstation. The content of this file could be just the text that must be interpreted, or pictorials combined with text, or statistical data related to a particular application of a component, or in the ultimate degree of sophistication, a video "slide-show" of scenes taken in an actual maintenance scenario depicting the problems encountered.

(Continued)

Table G-1. Key to Supportability Data Types, Sources, and Application (Cont'd-2)

NAME	TYPE OF DATA	REMARKS
1. DESIGN GUIDANCE (cont'd)		
g. Design Rules	Text	Prepared by the supportability engineers.
	Information Resident in a Data Base Management System	This is one of the objectives of ULCE. A random access data base would permit searching and visual display on a screen of design rules that pertain to the particular design or facet of design in the CAE workstation. The content of this file could be just the text that must be interpreted or pictorials combined with text.
2. ALLOCATIONS		
a. Supportability Requirements	Text	Prepared from specified requirements and knowledge of system division and complexity.
	Pictorial Screen Display	This would be in the form of the diagram or mechanical layout of the item being designed. The contents of the display indicate functional properties, as these determine performance, as well as physical features, as these determine the construction of the object; no more or no less than the design engineer is generating at this time. An alternative output would be a physical drawing that can be reviewed and annotated by the specialist
b. Feedback After Analyses	Text	Prepared by comparing analyses with allocations. If done manually, it is usually in the form of a chit.
	Pictorial Screen Display	This would be in the form of the diagram or mechanical layout of the item being designed. The contents of the display indicate functional properties, as these determine performance, as well as physical features, as these determine the construction of the object; no more or no less than the design engineer is generating at this time. An alternative output would be a physical drawing that can be reviewed and annotated by the specialist
c. Optimum Repair Level Analysis (ORLA)	Text	This is the output of an analysis, in the form of a table or graph, depicting the life cycle cost versus several repair decisions that were modeled in a reasonably simple mathematical analysis. Inputs and outputs to the ORLA are identical to those of a life cycle cost model. The tabulation can also appear on the screen rather than on a printout.

(Continued)

Table G-1. Key to Supportability Data Types, Sources, and Application (Cont'd-3)

NAME	TYPE OF DATA	REMARKS
2. ALLOCATIONS (cont'd)		
d. Specified Techniques	Text	Interpretation of this text provided by the government in the form of applicable specifications and data item descriptions selects the various models that are available for analyses and trades to be performed later. Allocations towards these analyses or trades are simply the determination of acceptable bounds as concerns the outcome of the analyses and trades (Items 4 and 5).
3. EQUIPMENT DESIGN		
a. Performance Requirements	Text	From specification for human interpretation and design rule preparation.
b. Schedules	Text	From the RFP and contract for human interpretation and design rule preparation.
c. Costs	Text	From negotiated proposal for human interpretation and design rule preparation.
d. Design Reviews	Text	Presently the data consist of statements critiquing the design being reviewed. In the future, it is conceivable that the design review will take place at the CAE terminal or at a parallel terminal and will be in the form of messages transmitted to the designer using windowing techniques or note pad techniques. The source of this information will be manually input by the design reviewer or result, when possible, from a comparison of the allocations with the results of the analyses (Item 4).
e. Allocations (see also Item 2)		Allocations have different formats as described in the following paragraphs. They are prepared by the supportability engineers from the specified requirements, system division, and estimate of complexity.
(1) Reliability	Text	The format is either a hard copy table consisting of an item's name, its reference designator, which is alpha-numeric, and a number containing several decimal places. The allocations can also be in the form of an LSAR format (Item 1).
(2) Maintainability	Text	The format is either a hard copy table consisting of an item's name, its reference designator, which is alpha-numeric, and a number containing several decimal places. The allocations can also be in the form of an LSAR format (Item 1).

(Continued)

Table G-1. Key to Supportability Data Types, Sources, and Application (Cont'd-4)

NAME	TYPE OF DATA	REMARKS
3. EQUIPMENT DESIGN (cont'd)		
e. Allocations (cont'd)		
(3) Partitioning	Pictorial	Normally this consists of marking up a signal flow diagram or a block diagram with boundaries of lower level assemblies. It is conceivable that this can be done directly on the terminal using a light pen or a mouse, after which each zone would become a separate drawing to be handled individually in the equipment design process. Each of these zones would then have its own identity in the work breakdown structure of an equipment (e.g., reference designator or LCN).
(4) Testing	Text	A description of the test facilities to be incorporated in the design for human interpretation and design rule preparation. This is prepared by the maintainability engineer from the specifications and block diagram reviews.
	Pictorial	Annotations of schematics, signal flow, or block diagrams of an electronic equipment depicting location of test points. The annotation could be provided by a design specialist working a second CAE workstation, which would then update the information contained in the main CAE workstation.
(5) Skill	Text	A number representing the skill level to be used to perform maintenance on the item being designed. This is for human interpretation and design rule preparation. This information is prepared by the maintainability engineer from the specified maintenance concept.
(6) Parts	Text	Parts allocations are derived by the design engineer from a table of preferred parts prepared by the reliability engineer. The design engineer chooses in accordance with other competing design requirements. The first cut parts list would contain the information through military or vendor part numbers. The gross reliability would be calculated from analyses (Item 4).
f. Feedback After Analyses	Text	Prepared by comparing analyses with allocations. If done manually, it is usually in the form of a chit.

(Continued)

Table G-1. Key to Supportability Data Types, Sources, and Application (Cont'd-5)

NAME	TYPE OF DATA	REMARKS
3. EQUIPMENT DESIGN (cont'd)		
f. Feedback After Analyses (cont'd)	Pictorial Screen Display	This would be in the form of the diagram or mechanical layout of the item being designed. The contents of the display indicate functional properties, as these determine performance, as well as physical features, as these determine the construction of the object; no more or no less than the design engineer is generating at this time. An alternative output would be a physical drawing, which can be reviewed and annotated by the specialist.
4. ANALYSES		
a. Performance Information	Text	The text is a string of descriptors. A string represents a performance attribute and contains the information where this attribute leaves or is output from the unit in question (e.g., a connector pin). A string may also contain reference to input stimuli that cause this particular output. MIL-STD-2076, Appendix A, contains an exhaustive listing of the nomenclature and units of measure associated with electronic parameters. There are two sources of these parameters. One is from written statements of tabulations supplied by the design engineer and the other could be provided by a performance analyses program working on conjunction with a computerized schematic and connectivity information.
	Pictorial	The pictorial data would consist of waveshapes or timing diagrams. Their source would be the same as for the text.
b. Design Information	Text	The data completely describe the unit in question. They contain physical attributes such as size, weight, dimensions together with tolerances, and sufficient descriptors that link each dimension to the portion of the object that it describes. The information also contains fasteners in which the type, size, physical attributes, and spacing between fasteners is given. If torque values are significant to mechanical strength, those are given also. The information requirements are those of the analyses to be performed on the design. See MIL-STD-1388's data dictionary for the design information required. The parts lists will also contain fastener information, subassemblies, etc., as obtained from the bill of materials contained on the assembly drawings.

(Continued)

Table G-1. Key to Supportability Data Types, Sources, and Application (Cont'd-6)

NAME	TYPE OF DATA	REMARKS
4. ANALYSES (cont'd)		
b. Design Information (cont'd)	Pictorial	This information supplies the connections on a schematic, the parts location on an assembly drawing, and, in general, the relation of one part to another and of tolerances to nominal values of components, mounting holes, and fasteners. This type of information is necessary for human intervention in the analyses procedures even if the design information was supplied automatically to other analyses techniques. Typical of such requirements are human factors analysis, which require visualization of the tasks to be performed, the preparation of step-by-step maintenance tasks, as well as the order of the tasks, the calculation of task times, the assessment of ease of maintenance and compliance with safety guidelines.
	Three-Dimensional Representation	Data sufficient to depict the object in three dimensions so that it can be rotated and dissected by the analyst would be extremely helpful in assessing access problems, human factors, handling and transportation, safety, etc.
c. Reliability, Maintainability, & Supportability (R,M&S) Metrics		The R,M&S metrics are listed in the order in which they are obtained and used during the design process.
(1) First Cut Mean Time Between Failures (MTBF)	Text	From parts information obtained from the bill of materials. Stresses are estimated from the worst case environmental requirements as obtained from the performance specification.
(2) First Cut Mean Time to Repair or Mean Corrective Maintenance Time (MTTR/M_{ct})	Text	Estimates based on regression analyses from MIL-HDBK-472 or from engineering estimates based on similar designs.
(3) First Cut Testability	Text	From regression analyses as provided in MIL-STD-2076. Information is usually obtained from functional block diagrams and discussions of design concepts.
(4) Electrical Stress Analyses	Text	Circuit analysis is performed on the schematic with knowledge of the parts, parts ratings, and tolerances, which are obtained from the parts lists. Performance information is also required and is usually obtained from the design specification for the item being analyzed.

(Continued)

Table G-1. Key to Supportability Data Types, Sources, and Application (Cont'd-7)

NAME	TYPE OF DATA	REMARKS
4. ANALYSIS (cont'd)		
c. R,M&S Metrics (cont'd)		
(5) Thermal Stress Analyses	Text	Information is obtained from the electrical stress analysis, the mechanical construction of the item, and cooling air flow from mechanical design information or thermal budgets. Convection and radiation calculations are made from mechanical layout of the next higher assembly.
(6) Vibration and Other Physical Stress Analyses		Information is obtained from mechanical drawings of the next higher assembly, the mounting information, and information provided by specifications regarding the environment.
(7) Reliability (MTBF)	Text	The formal analysis is performed from the results of the electrical stress, thermal stress, and vibration/environmental analyses, in addition to the final parts list as it appears on the assembly drawings.
(8) Reliability Block Diagram	Pictorial	The block diagram is made from circuit analysis from the schematics of the item analyzed as well as the next higher assembly and knowledge of the performance requirements obtained from the item's specifications.
(9) System MTBF	Text	The analyses are performed from the reliability block diagram and the individual reliability analyses of the system components.
(10) Assembly/Disassembly Task Times	Text	The analyses are performed by performing time and motion studies from information obtained from the assembly drawings or mock-ups. Tasks difficult to imagine are actually simulated.
(11) Checkout Procedures Task Times	Text	Checkout procedures are prepared from the schematics and the performance requirements of the item being analyzed. The task times are developed from the knowledge of the type of test equipment that will be used and time and motion study tables related to the use of this test equipment for any particular measurement.

(Continued)

Table G-1. Key to Supportability Data Types, Sources, and Application (Cont'd-8)

NAME	TYPE OF DATA	REMARKS
4. ANALYSIS (cont'd)		
c. R,M&S Metrics (cont'd)		
(12) Fault Isolation Procedures Task Times	Text	Fault isolation procedures are prepared from the test procedures by preparing fault trees for each of the performance requirements of a test procedure. Task times are developed by imagining that each has failed in one or more states, depending on the tolerances specified for each performance attribute. Tolerances are obtained from the performance specification for the item analyzed. (This is usually prepared by the contractor's systems engineer.)
(13) Mean Time to Repair MTTR or Mean Corrective Maintenance Time ($\bar{M}ct$)	Text	Analysis is performed from the parts list obtained from the assembly drawing, the failure rate of each of the parts, the assembly/disassembly task times, the checkout procedure task times, the fault isolation task times, and the connect and disconnect task times, which are all available from the previous task time calculations.
(14) Failure Modes, Effects, and Criticality Analyses (FMECA)	Text	These analyzes are made from the item's specified performance requirements, as well as the next higher assembly's performance requirements, the reliability block diagram, and mission requirements.
(15) Sneak Circuit Analysis	Text	There are no metrics for this analyses except to identify sneak paths that must be eliminated. The analysis is performed from the schematic and knowledge of the performance requirements from the specification for the item as well as its next higher assembly.
(16) Fault Isolation Indices	Text	The indices are measured in terms of ambiguity and fault isolation for a particular percentile of probable failures. The analysis is performed from the fault isolation procedures and failure rate information.
(17) Fault Detection Ratio	Text	The metric is the percent failure rate that can be detected by some means, such as built-in-test or test equipment. Analysis is performed from the checkout procedures, or if built-in-test is involved, the built-in-test routine and the failure rates.

(Continued)

Table G-1. Key to Supportability Data Types, Sources, and Application (Cont'd-9)

NAME	TYPE OF DATA	REMARKS
4. ANALYSIS (cont'd)		
c. R,M&S Metrics (cont'd)		
(18) Built-In-Test Analysis	Text	The metrics are fault detection capability in terms of percent of failure rate detected, fault isolation capability in terms of failure rate isolated unambiguously, and false alarm rate. The first two analyses are performed in a fashion similar to Items (16) and (17) above, basing the analyses on a detailed performance description of the built-in-test circuits. The false alarm rate is calculated from knowledge of the built-in-test performance regarding particularly the safeguards built into the evaluation of each built-in-test alarm and its correlation with other observed symptoms, or the passing of time. Detailed performance descriptions are required for this purpose.
(19) Manpower Skill Levels and Quantity	Text	This analysis is performed from the maintenance task time analysis of Items (10), (11), and (12), and a description of manpower capabilities as provided by the government.
(20) Test Equipment Compatibility	Text	This has no metric. The item under analysis is either compatible or not. Incompatibilities must be corrected. The analysis is a tedious and difficult task in which the test requirements are matched to the test equipments capabilities. This matching includes the performance tolerances as specified, as well as the test equipment's measurement tolerances as provided from information concerning the test equipment. Tolerance excursions are examined to ensure compatibility. Physical compatibility is ascertained by assessing the UUT's connectors' compatibility with the test equipments' main connectors. The information is obtained from the UUT's assembly drawings and the information provided about the test equipment.
(21) Life Cycle Cost	Text	The metrics are development cost, acquisition cost of the production item, and support costs. Inputs concerning government-controlled factors such as useful life, labor rates, etc., are provided by the government. The other inputs are obtained directly or developed from the reliability, maintainability, manpower, and test equipment analyses described above.

(Continued)

Table G-1. Key to Supportability Data Types, Sources, and Application (Concluded)

NAME	TYPE OF DATA	REMARKS
4. ANALYSIS (cont'd)		
c. R,M&S Metrics (cont'd)		
(22) Level of Repair Analyses	Text	There is no metric associated with this other than cost per particular maintenance level (e.g., repair at the organizational level, repair at the intermediate level, repair at the depot level, etc.). Level of repair analyses are merely iterated from life cycle cost analyses testing the support costs at the various levels of maintenance.
d. Reviews and Validations	Text	Presently the data consist of statements critiquing the design being reviewed. In the future, it is conceivable that the design review will take place at the CAE terminal or at a parallel terminal and will be in the form of messages transmitted to the designer using windowing techniques or note pad techniques. The source of this information will be manually input by the design reviewer or result, where possible, from a comparison of the allocations with the results of the analyses (Item 4).
5. TRADES		
a. Analysis Data	Text	The text will consist primarily of figures of merit, which are linked to the item in question by an alpha-numeric code such as a reference designator or logistics control number in accordance with MIL-STD-1388. Text may accompany these data in the form of remarks or a written report to be analyzed by the review team. The format of the metrics will be that described in MIL-STD-2176, Appendix A, and if a Logistics Supportability Analysis (LSA) is involved, as described in MIL-STD-1388. Trades usually consist of permutating the analysis performed in Item 4 to decide sensitivity of the output to variation of independent variables of the analyses. Other analyses procedures may be introduced, such as life cycle costs, manufacturing costs, or changes in maintenance concepts, etc. The data type for these new analyses are the same as in Item 4.
b. Re-Allocations		See Item 3e.
c. Define Degrees of Freedom	Text	This text is in the form of a specification prepared by the design evaluation team to be read and interpreted by the analyst.

Appendix H

APPLICABLE MILITARY SPECIFICATIONS

Table H-1 contains the first-tier specifications and standards found in a system specification and Integrated Logistics Support (ILS) specifications. Each of these contain subordinate specifications; the design requirements are so detailed that they leave little freedom for innovation.

Table H-2 lists those specifications and standards applicable to reliability, maintainability, and supportability (R,M&S) design-related analyses.

Table H-1. List of Generally Imposed Specifications and Standards

SPECIFICATION	TITLE
SPECIFICATIONS:	
MIL-T-981	Transformer, Power Voltage Regulating
MIL-R-2765	Rubber Sheet, Strip Extruded and Molded Shapes, Synthetic, Oil Resistant
MIL-M-3171	Magnesium Alloy, Processes for Pretreatment and Prevention of Corrosion on
MIL-G-3787	Glass, Laminated, Flat (Except Aircraft)
MIL-C-3849	Cord, Electrical (Tinsel)
MIL-E-5400	Electronic Equipment, Aerospace, General Requirements for
MIL-G-5514	Gland Design Packings, Hydraulic, General Requirements for
MIL-P-5516	Packing, Performed, Petroleum Hydraulic Fluid Resistant, 160 Degrees F
MIL-C-5541	Chemical Conversion Coatings on Aluminum and Aluminum Alloys
MIL-P-7788	Panels, Information, Integrally Illuminated
MIL-T-7928	Terminals, Lug: Splices, Conductor: Crimp Style, Copper, General Specification for
MIL-A-8625	Anodic Coatings, for Aluminum and Aluminum Alloys
MIL-S-8660	Silicone Compound
MIL-Q-9858	Quality Program Requirements
MIL-C-11693	Capacitors, Feed Through, Radio Interference Reduction, AC and DC. (Hermetically Sealed in Metallic Cases). Established and Non-Established Reliability, General Specification for
MIL-R-12934	Resistor, Variable, Wirewound, Precision, General Specification for
MIL-C-14550	Copper Plating (Electrodeposited)
MIL-P-15024	Plates, Tags and Bands for Identification of Equipment
MIL-P-15024/5	Plates, Identification
MIL-E-15090	Enamel, Equipment, Light-Gray (Formula No. 111)
MIL-C-15370	Couplers, Directional (Coaxial Line or Waveguide) General Specification for

(Continued)

Table H-1. List of Generally Imposed Specifications and Standards (Cont'd-2)

SPECIFICATION	TITLE
MIL-R-15624	Rubber Gasket Material 40 Durometer Hardness (Maximum)
MIL-F-15733	Filter, Radio Interference, General Specification for
MIL-F-16552	Filters, Air Environmental Control System Cleanable Impingement (High Velocity Type)
MIL-I-16923	Insulating Compound, Electrical, Embedding
MIL-M-17214	Indicator, Permeability; Low-Mu (Go-No Go)
MIL-M-17508	Mounts, Resilient Types 6E200, 6E900, 6E900BB, 7E450, 7E450BB, 6E150, 6E100
MIL-F-18327	Filters; High Pass, Low Pass, Band Pass, Band Suppression, and Dual Functioning, General Specification for
MIL-C-18388	Coils, Tube Deflection; and Coils, Tube Focusing
MIL-C-19978	Capacitors, Fixed, Plastic (or Paper-Plastic) Dielectric (Hermetically Sealed in Metal, Ceramic, or Glass Cases), Established and Non-Established Reliability, General Specification for
MIL-A-21180	Aluminum-Alloy Castings, High Strength
MIL-E-21981	Electronics Type Designations, Identification Plates and Markings, Requirements for
MIL-C-22520	Crimping Tool, Terminal, Hand, Wire Termination, General Specification for
MIL-T-22910	Tools, Crimping, Hand, For Crimp Style Electric Terminals and Shield Ferrules
MIL-C-23183	Capacitors, Fixed or Variable, Vacuum Dielectric General Specification for
MIL-C-26074	Coatings, Electroless Nicket, Requirements for
MIL-C-28777	Cable Assembly, Power Electrical
MIL-C-39001	Capacitors, Fixed Mica Dielectric, Established Reliability, General Specification for
MIL-C-39003	Capacitors, Fixed, Electrolytic, Solid Electrolyte, Tantalum, Established Reliability, General Specification for
MIL-C-39006	Capacitor, Fixed, Electrolytic (Nonsolid Electrolyte) Tantalum, Established Reliability, General Specification for
MIL-C-39018	Capacitors, Fixed, Electrolytic (Aluminum Oxide), General Specification for

(Continued)

Table H-1. List of Generally Imposed Specifications and Standards (Cont'd-3)

SPECIFICATION	TITLE
MIL-T-43435	Tape, Lacing and Tying
MIL-G-45204	Gold Plating, Electrodeposited
MIL-C-45662	Calibration System Requirements
MIL-R-46085	Rhodium Plating, Electrodeposited
MIL-C-55514	Capacitors, Fixed Plastic (or Metalized Plastic) Dielectric DC in Nonmetal Cases, Established Reliability, General Specification for
MIL-C-55543	Cable, Electrical, Flat Multiconductor, Flexible, Unshielded
MIL-C-55544	Connectors, Electrical, Environmental Resistant, for Use with Flexible Flat Conductor Cable and Round Wire, General Specification for
MIL-T-55619	Tools, Crimping, for Coaxial, Radio Frequency, Connectors, General Specification for
MIL-C-81562	Coating, Cadmium and Zinc (Mechanically Deposited)
MIL-P-81728	Plating, Tin Lead (Electrodeposited)
STANDARDS:	
MIL-STD-108	Definitions of and Basic Requirements for Enclosures for Electric and Electronic Equipment
MIL-STD-143	Standards and Specifications, Order of Precedence for the Selection of
MIL-STD-198	Capacitors, Selection and Use of
MIL-STD-217	Reliability Prediction of Electronic Equipment
MIL-STD-242	Electronic Equipment Parts (Selected Standards)
MIL-STD-275	Printed Wiring for Electronic Equipment
MIL-STD-415	Test Provisions for Electronic Systems and Associated Equipment, Design Criteria for
MIL-STD-454	Standard General Requirements for Electronic Equipment
MIL-STD-461	Electromagnetic Interference Characteristics, Requirements for Equipment
MIL-STD-462	Electromagnetic Interference Characteristics, Measurement of

(Continued)

Table H-1. List of Generally Imposed Specifications and Standards (Cont'd-4)

SPECIFICATION	TITLE
MIL-STD-469	Radar Engineering Design Requirements, Electromagnetic Compatibility
MIL-STD-470	Maintainability Program for Systems and Equipment
MIL-STD-721C	Definitions of Effectiveness Terms for Reliability, Maintainability, Human Factors, and Safety
MIL-STD-749	Preparation and Submission of Data for Approval of Nonstandard Parts
MIL-STD-756	Reliability Modeling and Prediction
MIL-STD-785	Reliability Program for Systems and Equipment, Development and Production
MIL-STD-810	Environmental Test Methods
MIL-STD-882	System Safety Program for Systems and Associated Subsystems and Equipment, Requirements for
MIL-STD-1326 (EC)	Test Point, Test Point Selection, and Interface Requirements Monitored by Shipboard On-Line Automatic Test Equipment
MIL-STD-1364	Standard General Purpose Electronic Test Equipment
MIL-STD-1388-1	Logistics Support Analysis
MIL-STD-1388-2	Logistics Support Analysis Record, DoD Requirements for a
MIL-STD-1472	Human Engineering Design Criteria for Military Systems Equipment and Facilities
MIL-STD-1519 (USAF)	Test Requirements Documents, Preparation of
MIL-STD-1629	Procedures for Performing a Failure Mode, Effects, and Criticality Analysis
DoD-STD-1701	Hardware Diagnostic Test Systems Requirements
MIL-STD-1843	Reliability-Centered Maintenance for Aircraft, Engines and Equipment
MIL-STD-2076 (AS)	Unit Under Test Compatibility with Automatic Test Equipment, General Requirements for
MIL-STD-2077 (AS)	Test Program Sets, General Requirements for
MIL-STD-2155	Failure Reporting, Analysis and Corrective Action System
MIL-STD-XXX (USAF)	Universal PIN Mapping Standard for Interface Between Test System and Unit Under Test (UUT)

(Continued)

Table H-1. List of Generally Imposed Specifications and Standards (Cont'd-5)

SPECIFICATION	TITLE
HANDBOOKS:	
MIL-HDBK-176	Guidance for Flexible Flat Multiconductor Cable (Flat Conductors)
MIL-HDBK-217	Reliability Modeling and Prediction
MIL-HDBK-225	Synchros Description and Operation
MIL-HDBK-338	Electronic Reliability Design Handbook
MIL-HDBK-472	Maintainability Prediction
MIL-HDBK-XXX	System Hardware/Software Reliability
MIL-HDBK-XXX	Non-Electronic Reliability Handbook
PUBLICATIONS:	
IEEE-STD-488-1978	Digital Interface for Programmable Instrumentation
RADC-TR-70-89	ARINC Fault Symptom Model
DoD-T-86000	Test Requirements Document, Preparation of

(Concluded)

Table H-2. Specifications and Standards for R,M&S Design Related Analyses

ANALYSIS TYPE	SPECIFIED BY
1. RELIABILITY ANALYSES:	MIL-STD-1388-1A, Task 301
a. Parts failure rate catalogue for allocations and worst-case analyses.	MIL-HDBK-217
(1) Lessons learned failure rate feedback to modify a.	MIL-STD-1388-1A, 501.2
(2) Mission thermal, mechanical stress, and profile for application in catalogue search.	MIL-STD-1388-1A, 301.2.4
b. Reliability predictions.	MIL-STD-785, Task 203 MIL-STD-756,MIL-HDBK-217, MIL-STD-1543 (USAF)
(1) Basic prediction from parts application, packaging, and functional configuration of the design.	MIL-STD-785, Task 203 For use in FMECA and MIL-STD-1388-2A Data Record B.
(a) Circuit analysis to determine electrical stresses under operating conditions.	Iterate (1) and identify overstress.
(b) Circuit analysis to determine thermal stresses under operating conditions.	Iterate (1) and identify overstress.
(c) Construction analysis to determine physical stresses under operating conditions.	Iterate (1) and identify overstress.
(2) Mission reliability prediction based on functional block diagram, mission profiles, operational scenarios, redundancies, work-arounds, degradations, etc.	MIL-STD-785, Task 203 For use in FMECA and Mil-STD-1388-2A Data Record B.
(3) Construction of reliability block diagram for use in other analyses such as FMECA, BIT and Test Point, LSAR, etc.	MIL-STD-785, Task 203 For use in FMECA and MIL-STD-1388-2A Data Record B.
c. Failure modes, effects and criticality analysis.	MIL-STD-785, Task 204 MIL-STD-1388-1A, Task 301.2.4.1.
(1) Functional block diagram of the item under analysis for use in the FMECA, maintainability analysis, LSAR and technical manuals.	MIL-STD-1629, Task 101, 4.1.4.

(Continued)

Table H-2. Specifications and Standards for R,M&S Design Related Analyses (Cont'd-2)

ANALYSIS TYPE	SPECIFIED BY
(2) Failure modes and effects analysis hardware approach.	MIL-STD-1629, Task 101
(a) Top-down technique.	
(b) Bottoms-up technique.	
(3) Failure modes and effects analysis functional approach.	
(a) Top-down technique (preferred for later use in BIT, test point, maintainability and maintenance task analyses, as well as in developing fault isolation strategies).	
(b) Bottoms-up technique.	
(4) Some combination of (a) and (b).	
(5) Criticality analysis	MIL-STD-1629, Task 102
(a) Qualitative approach.	
(b) Quantitative approach.	
(c) Construction of criticality matrix.	
(6) FMECA maintainability information. This would require the combining of other analytical results such as from a BIT and test point analysis.	
d. Sneak circuit analysis. Also for input to, or use in BIT and test point analyses, testability analysis, construction of test procedures, etc.	MIL-STD-785, Task 205
e. Electronics parts/circuit tolerance analysis. For use in design evaluation, risk analysis and reliability prediction.	MIL-STD-785, Task 206
f. Reliability centered maintenance	MIL-STD-1388-1A, Task 301.2.4.2, MIL-STD-785, Task 209
g. Parts control	MIL-STD-785, Task 207 MIL-STD-1388-1A, Task ⌣01
(1) Design guides including junction temperatures allowed derating requirements, parts application margins of safety, etc.	MIL-HDBK-XXX, MIL-HDBK-338
(2) Identification of reliability critical items.	M TD-785, Task 208

(Continued)

Table H-2. Specifications and Standards for R,M&S Design Related Analyses (Cont'd-3)

ANALYSIS TYPE	SPECIFIED BY
h. Reliability risk analysis.	MIL-STD-1388-1A, Task 301.2.3
2. MAINTAINABILITY ANALYSES:	MIL-STD-1388-1A, Task 300
a. Elemental maintenance actions catalogue including maintenance time skills.	MIL-STD-1388-1A, Task 300.2.4, MIL-HDBK-472
(1) Lessons learned feedback for task times and difficulties.	MIL-STD-1388-1A, Task 501.2
(2) Maintenance/use profile input to adjust elemental task times and skills.	MIL-STD-1388-1A, Task 301.2.4
b. Maintenance access analysis.	MIL-STD-280
c. Operating and maintenance task analysis for inputs to the maintainability prediction, technical manuals and LSAR.	MIL-STD-1388-1A, Task 301.2.4.3
d. Maintainability prediction.	MIL-STD 470, MIL-HDBK-472
(1) MIL-HDBK-472, Procedure 1.	
(2) MIL-HDBK-472, Procedure 2. There are many adaptations of this procedure. It is the most rigorous.	
(3) MIL-HDBK-472, Procedure 4.	
(4) ARINC Fault Symptom Model.	RADC-TR-70-89
e. Built-in-Test Analysis. For use in design analysis, integrated diagnotics trades, operational availability predictions, LSAR, etc.	MIL-STD-1388-1A, Task 301.2.4
f. Testability analysis. Used for design analysis, test point placement.	MIL-STD-1388-1A, Task 301.2.4
(1) UUT compatibility with automatic test equipment. For use in design analysis, integrated diagnostics trades, preparation of test requirements, LSAR, etc.	MIL-STD-2076
(2) Test time analysis.	MIL-HDBK-472

(Continued)

Table H-2. Specifications and Standards for R,M&S Design Related Analyses (Cont'd-4)

ANALYSIS TYPE	SPECIFIED BY
3. ITEMS FOR AUTOMATIC TESTING TECHNOLOGY:	
a. Test point selection.	MIL-STD-1326(EC)
b. Test requirements analysis.	MIL-STD1519 (USAF)
c. Diagnostics analysis.	MIL-STD-1701
d. Test equipment compatibility analysis.	MIL-STD-2076(AS)
(1) Test program requirements determination.	MIL-STD-2077(AS)
(2) Test procedure requirements.	DoD-T-86000(NS)
(3) Interface analysis.	MIL-STD-XXX(USAF), IEEE-STD-488-1978
4. ITEMS FOR INTEGRATED LOGISTICS TASKS:	
a. Level of repair analyses.	MIL-STD-1388-1A, Task 303
b. Life cycle cost analyses.	MIL-STD-1388-1A, Task 303, Logistic Support Cost (LSC) model
c. Reliability centered maintenance.	MIL-STD-1843 (USAF)
d. Integrated diagnostics trade-off.	MIL-STD-1388-1A, Task 303
e. Design interface compatibility checks:	
(1) Check on connector pin assignments versus signal names, signal types, and signal tolerances. For checking designs (for interfacing), inputs to be support equipment, test and calibrations requirements, and inputs to technical manuals.	Good design practices
(2) Check on signal names from signal origin to destination through the signal flow diagrams as well as the schematics. For design analysis and technical manuals source material accuracy check.	Good design practices

(Concluded)

Appendix I

LIFE CYCLE COST MODEL INPUT DATA

This appendix lists each contractor input to the life cycle cost (LCC) model. These inputs are the results of the data generation and collection described in Section III.D of the text. The variables are defined, the Air Force constants are given, and a check for data consistency is presented.

A. VARIABLES

1. System Variables

The system variables and definitions are arranged in the order of appearance on the computer printout data sheets.

TCB: Cost of Training Per Man at Base Level Including Instructions and Training Materials. Training estimates are extracted from the training requirements proposed in the Training Planning Information Document Data Item AOOJ. From the total training course outlined for the organizational and intermediate level, it is estimated that two days training per line-replaceable unit (LRU) will be required for intermediate-level maintenance.

In computing the cost of training, it is assumed that there are 10 students per instructor and the cost of training materials is $10 per student per day. The labor rates used are $11.70/hour for base-level personnel and $14.91/hour for instructors, which are the government's base labor rates. Therefore, for each LRU, the cost of training per man is calculated as follows:

TCB = (Number of Days Required per LRU) x (No. Hours Per Day)
x (Trainee Labor Rate + Instructor Rate/No. Students Per Instructor)
+ (Materials Cost Per Day) x (No. of Days Per LRU).

Substituting the Constants:

TCB = (2 Days) x (8 Hours) x (11.70 + 14.91/10 Students) + ($10)
x (2 Days) = $231.06 per LRU.

TCD: Cost of Training Per Man at Depot Including Instructions and Training Materials. Since many of the shop-replaceable units (SRUs) display similar configurations, it is estimated that one-half day of training for each repairable SRU is required.

Labor rates used are \$12.44/hour for depot-level personnel and \$14.91/hour for instructors, which are the government's depot labor rates. In computing the cost of training, it is assumed that there are 10 students per instructor and the cost of training material is \$10 per student per day; therefore, for each SRU the cost of training is calculated as follows:

TCD = [(No. of Days Required Per SRU) x (No. of Different Repairable SRUs)
x (No. of Hours Per Day) x (Trainee Labor Rate
+ Instructor Labor Rate)/(No. Students per Instructor)]
+ [(Materials Cost Per Day) x (No. Days Required Per SRU)].

Substituting the Constants:

TCD = (1/2) x (No. of Different Repairable SRUs) x (8 Hours)
x (\$12.44 + \$14.91/10 Students) + (\$10) X (1/2 Day).

TCD = (\$55.72 x No. of Different Repairable SRUs) + \$5.00.

TE: Cost of Peculiar Training Equipment. The training equipment required for each system consists of the system itself in the form of a bench mock-up, plus the required support equipment. The AN/ALQ-XXX test set is capable of intermediate- as well as depot-level maintenance; therefore one test set is sufficient to train both intermediate- and depot-level personnel. It is assumed that one of the two test sets quoted as support equipment is for training. So as not to charge twice for this set, TE is set to zero.

H: Number of Pages of Depot-Level Technical Orders and Special Repair Instructions. Based on the technical order page count quoted in the cost proposal, data item AOOL, the page count for the depot-level manuals, which consist of overhaul instructions and an illustrated parts breakdown list is 429 pages.

JJ: Number of Pages of Organizational- and Intermediate-Level Technical Orders. Based on technical order page count quoted in the cost proposal, the page count for the intermediate-level technical orders, which include a description section, schematics, and diagnostics, is 363 pages.

Since there is no organizational-level technical order required to be quoted, it is assumed that the description section of the intermediate-level technical order will suffice for both purposes. Therefore, no additional costs are estimated or input.

BPA: Cost of Additional Peculiar Support Equipment Required for the Subsystem at the Intermediate Maintenance Level. The input for BPA is the cost of one set of peculiar support equipment consisting of the AN/ALQ-XXX test set and mobile bench.

DPA: Cost of Additional Peculiar Support Equipment Required at the Depot Level. The input for DPA is one set of peculiar support equipment also consisting of the AN/ALQ-XXX test set as required by the RFP.

N: Number of LRUs in the Subsystem.

N = 22.

2. Line-Replaceable Units, Shop-Replaceable Units Variables

The LRU (SRU) variables and definitions are arranged in the order of appearance of the data on the computer printout sheets.

QPA (SQPA): Quantity of an LRU (SRU) in the Subsystem (LRU). The quantities are those of the equipment assembly drawings.

UC (SUC): Unit Cost for the LRU (SRU). Spares acquisition costs for LRUs and SRUs are derived from the contract line items by dividing the total de-escalated cost by the quantity bought at the earliest assumed spares buy. This coincides with the costs of line items 0027 and 0032. SRU spares costs are obtained from the cost breakdown of the LRUs. Since the spares quantities are small compared to the production lot to which they are added, no learning curve is used. The costs are de-escalated to FY 1982 dollars, as required.

MTBF (SMTBF): Mean Time Between Failures for the LRU (SRU). MTBF estimates are obtained from reliability estimates performed on the proposed AN/ALQ-XXX and are traceable to documented reliability analyses and predictions. All reliability data reflect the system status for production. The required maintenance derate factor of 3 is applied to obtain mean operating time between maintenance actions (MOTBMA) and system MOTBMA ((S)MOBMA). The program was changed as follows to incorporate this:

(S)MOTBMA - (S)MTBF/(3 x UF).

RIP: Fraction of Failures of an LRU that can be Repaired in Place. RIP is deliberately set to 0 because it was observed that the LCC program would calculate zero

cost for higher level maintenance for all items for which RIP was greater than 0, resulting in unrealistically low support costs. This was done, although the control indicator is lampable from the front, at the organizational level of maintenance. The lamp assemblies are easily accessible and pull out from the front panel without the use of tools, which obviates the need to remove the control indicator for lamp replacement. However, due to the low failure rates associated with this repair, the increase in support cost due to setting RIP to 0 is insignificant.

All LRUs RIP = 0.

RTS (SRTS): Fraction of LRU (SRU) Removals Expected to be Repaired at Base Level. In accordance with the contractual maintenance philosophy, all LRUs are repaired at the base level. However, it is estimated that 1 percent of LRUs may be returned to the depot for repairs associated with chassis wiring. Therefore, 99 percent will be repaired at the base. The antennas have limited repair possible, namely the detector diode and connectors can be replaced. These items represent 99 percent of the antenna's failures. SRUs are either repaired at the depot or discarded at the base. Only those SRUs that are physically non-repairable are modeled as discard.

- All LRUs: RTS = 0.99.
- All SRUs: SRTS = 0.

NRTS (SNRTS): Fraction of LRU (SRU) Removals Expected to be Returned to the Depot for Repair. According to the contractual maintenance philosophy, all LRUs are returned to the base for repair. However, two modes of failure might provide the necessity for a depot repair--repair of harness wiring or structural damage. All other failure modes can be repaired using the intermediate-level test set at the base. In addition, the design of the chassis cabling permits cable and connector repair at the intermediate level using the approved connector repair kit containing crimp tools. No difficult repair is required. In addition, harnesses are completely removable from the LRU for bench repair or complete replacement. Therefore, harness failure can always be maintained at the intermediate level. However, an NRTS rate of 1 percent has been estimated for an isolated case. Additional NRTS for return of LRUs to the depot due to accidental structural damage or periodic overhaul could not be modeled because ground rules are not provided for estimating frequency and extent of damage nor is an overhaul schedule provided.

All repairable SRUs are returned to the depot except in cases where the extent of malfunction renders the unit non-repairable (estimated as 1 percent).

- Antenna LRU: NRTS = 0.
- All other LRUs: NRTS = 0.01
- Repairable SRUs: SNRTS = 0.99
- Non-repairable SRUs: SNRTS = 0.

COND (SCOND): Fraction of LRU (SRU) Removals Expected to Result in Condemnation at the Base Level. For all LRUs other than the antenna, failures resulting in full condemnation will never occur. Therefore, this number is modeled as 0 for all other LRUs. Because the structure is the costliest part of the antenna, it would be impractical to attempt to salvage any component and replace a structure, as opposed to salvaging the structure when the detector or connector fails. COND is, therefore, input as follows:

- Antenna LRU: COND = 0.01.
- All other LRUs: COND = 0.

For repairable SRUs, it is estimated that 1 percent of the failures will be extensive enough to result in condemnation.

- Repairable SRUs: SCOND = 0.01.
- Non-repairable SRUs: SCOND = 1.

IMH: Average Man Hours to Perform Corrective Maintenance of the LRU In Place or On-Line Including Fault Isolation, Repair, and Verification. IMH is set to zero to be consistent with RIP.

All LRUs: IMH = 0.

RMH: Average Man Hours to Remove and Replace a Given LRU. RMH is obtained from the maintainability analysis for each LRU.

BMH (SBMH): Average Man Hours to Perform Intermediate-Level Maintenance on a Removed LRU (SRU) Including Fault Isolation, Repair, and Verification.

- For all LRUs, BMH is obtained from the maintainability analysis for each LRU.
- Since SRUs are not modeled as repaired at the base level, compliant to the contractual maintenance philosophy, SBMH = 0.

DMH (SDMH): Average Man Hours to Perform Depot-Level Maintenance on a Removed LRU (SRU) Including Fault Isolation, Repair, and Verification.

- For the LRUs, DMH is obtained from the maintainability analysis for each LRU.
- For the SRUs, SDMH is obtained from the maintainability analysis for each LRU.
- For non-repairable SRUs, SDMH = 0.

W (SW): Unit Weight of the LRU (SRU). Weights are obtained from engineering estimates.

PA (SPA) Number of New "P" Coded Repairable Assemblies within the LRU (SRU). For each LRU, PA is equal to the number of different repairable SRUs.

For each SRU, SPA is equal to the number of different non-standard repairable subassemblies. This is obtained from the assembly drawing's bill of materials. These are data inputs to the LCC because the model requests them even though they are not used in calculating support costs.

PP (SPP): Number of New "P" Coded Consumable Parts within the LRU (SRU). PP is equal to the number of different non-repairable, non-standard SRUs and piece parts contained within an LRU. The piece parts of an LRU comprise the chassis-mounted parts which are contained in the Miscellaneous Parts input.

SPP is obtained from an actual parts count for the current design. A part used in more than one SRU does not have to be added into the inventory again; therefore, SPP for multiple use parts is not necessarily an integer. These are data inputs to the LCC because the model requests them, even though they are not used in calculating support costs.

SP (SSP): Number of Standard Parts Per LRU (SRU). SP is equal to the number of standard piece parts in each LRU. These are contained in the Miscellaneous Parts input.

SSP is obtained from an actual parts count for the current design and accounts for multiple use parts.

NSRU: Number of SRUs Contained in a Given LRU. NSRU is obtained from the equipment assembly drawings.

UF: Ratio of Operating Hours to Flying Hours (Use Factor). UF is set equal to one for all LRUs and SRUs as instructed by the RFP.

3. SRU Variables

The following variables are peculiar to the subassembly.

SBMC: Average Material Cost Per Base Maintenance Action Expressed as a Fraction of the SRU Unit Cost (SUC).

- Since SRUs are not repaired at base level, SBMC = 0
- SBMC = 0 for all non-repairable SRUs.

SDMC: Average Material Cost Per Depot Maintenance Action Expressed as a fraction of the SRU Unit Cost (SUC).

- Since non-repairable SRUs are not sent to the depot, SDMC = 0 for these.
- For all repairable SRUs, SDMC is derived as a failure weighted average of the parts cost estimates divided by the SRU cost estimates. (See Figure I-1 for a sample calculation.) All percentages less than 1 percent have been rounded up to 1 percent parts cost for SRUs costing less than $1,000; therefore, most estimates are pessimistic and parts costs will, in reality, be lower than those calculated by the LSC.

Cost Analysis - Unit ABC - Voltage Regulator - LRU X

NO./ NOMENCLATURE	REF. DESIG.	QUANTITY	$\lambda/10^6$	UNIT COST (FY75$)	NλC
DC, Analog	VR1-9	9	27.8200	5.00	125.190
Relay	K1	1	0.1900	8.00	1.520
Switch	S1	1	0.0100	8.00	0.080
Capacitor	C1-C13	13	0.1560	0.50	1.014
Diode	CR1-6	6	0.1750	1.00	1.050
Resistor	R1-4	4	0.0005	2.00	0.122
		TOTAL	28.3800		128.976

$$\text{Average Material Cost} = \frac{\Sigma\ N\ \lambda\ \text{Cost}}{\Sigma\ N\ \lambda} = \frac{128.976}{28.38} = \$4.54$$

$$\text{SMDC} = \frac{\text{Average Material Cost}}{\text{Unit 410 Production Cost}} = \frac{\$4.54}{\$391} = 0.01$$

Figure I-1. Sample Parts Cost Estimate Calculation

4. Air Force Constants

The following constants are supplied by the Air Force for use in the modeling.

TFFH: Expected Tctal Force Flying Hours Over the Program Inventory Usage Period.

TFFH = 1,035,050 hours.

PFFH: Expected Peak Force Flying Hours for One Month During the Peak Usage Period.

PFFH = 8,625 hours per month.

PIUP: Operational Service Life of the Weapon System in Years (Program Inventory Usage Period.

PIUP = 10 years.

M: Number of Operating Base Locations.

M = 14 bases.

OS: Fraction of Total Force Deployed to Overseas Locations.

OS = 0.50.

OSTCON: Average Order and Shipping Time within the Continental United States.

OSTCON = 0.36 month.

OSTOS: Average Order and Shipping Time to Overseas Locations.

OSTOS = 0.53 month.

CONF: Confidence Factor Reflecting the Probability of Satisfying a Random Demand for a Spare Part of Serviceable Stock to Replace a Removed Part.

CONF = 0.90.

IMC: Initial Management Cost to Introduce a New Item (Assembly or Piece Part) into the Air Force Inventory.

IMC = $40.91 per item.

PSO: Average Packing and Shipping Costs to Overseas Locations.

PSO = \$0.99 per pound.

PSC: Average Packing and Shipping Cost to Continental United States Locations.

PSC = \$0.53 per pound.

RMC: Recurring Management Cost to Maintain a Line Item of Supply (Assembly or Piece Part) in the Wholesale Inventory System.

RMC = \$104.20 per item per year.

TD: Average Cost Per Page of Technical Documentation. The average acquisition cost of one page of the reproducible source document (does not include reproduction costs).

TD = \$220 per page.

SA: Annual Base Supply Line Item Inventory Management Cost.

SA = \$20.20 per item per year.

TR: Average Man Hours Per Maintenance Action to Complete Transaction Forms.

TR = 0.16 hour.

PMB: Direct Productive Man Hours Per Year at Base Level (Includes Touch Time, Transportation Time, and Set-up Time).

PMB = 1,500 hours per man per year.

PMD: Direct Productive Man Hours Per Year at the Depot Level (Includes Touch Time, Transportation Time, and Set-up Time).

PMD = 1,500 hours per man per year.

MRF: Average Man Hours per Maintenance Action to Complete On-Equipment Maintenance Records.

MRF = 0.24 hour.

MRO: Average Man Hours Per Maintenance Action to Complete Off-Equipment Maintenance Records.

MRO = 0.08 hour.

SR: Average Man Hours Per Maintenance Action to Complete Supply Transaction Records.

SR = 0.25 hour.

TRB: Annual Turnover Rate for Base Personnel.

TRB = 0.33.

TRD: Annual Turnover Rate for Depot Personnel.

TRD = 0.15.

BLR: Base Labor Rate.

BLR = $11.70 per man hour.

DLR: Depot Labor Rate.

DLR = $12.44 per man hour.

BMR: Base Consumable Material Consumption Rate. Includes minor items of supply (nuts, washers, rags, cleaning fluid, etc.) which are consumed during repair of items.

BMR = $2.28 per hour.

DMR: Same as BMR Except Refers to Depot-Level Maintenance.

DMR = $6.72 per hour.

BRCT (SBRCT): Average Base Repair Cycle Time.

BRCT (SBRCT) = 0.13 month.

DRCT (SDRCT): Average Depot Repair Cycle Time.

DRCT (SDRCT) = 1.84 months.

B. COSTS

1. Total Production Costs

The total recurring and non-recurring costs for the systems were obtained by de-escalating to FY 1982 dollars, for contract line items 0001, 0020, 0026, 0032, 0033, and 0034 in accordance with their individual scheduled delivery. The cost includes profit.

2. Initial Support Cost

These consist of one-time variable support cost factors required to establish an initial support system. The design attributes that have the largest influence on the initial support costs for the AN/ALQ-XXX are associated with spares and support equipment costs.

For checkout and fault isolation of the SRUs, the AN/ALQ-XXX test set has been approved. The test set is designed to verify proper SRU operation and to fault isolate to a replaceable component or group of components in those SRUs that are repairable. In addition to SRU-related support equipment, intermediate-level support equipment is contained in the test set for depot LRU testing. This test equipment is supplied in the event that LRU refurbishing, overhaul, or future modifications are required.

Support equipment costs reflect the equipment that is intended to be purchased consisting of common manual and some peculiar manual equipment housed in a convenient console. The design of the AN/ALQ-XXX permits a variety of support equipment types to be used for LRU/SRU repair and does not require any special skill beyond that available at a base level. The AN/ALQ-XXX is designed to be supportable by automatic test equipment. The built-in-test (BIT) features that provide fault isolating to the correct LRU for 98 percent of the detected failures provide information at LRU front panel test points and normal output connectors to permit automatic fault isolation to an SRU. These features permit cost-effective alternate support concepts to be modeled in addition to the basic LCC estimate.

3. Cost of First Line Unit Spares Required to Support the AN/ALQ-XXX

As required, spares costs are calculated with equation C1, whose inputs are: N, QPA, SQPA, UC, SUC, MTBF, MTBT (converted to MOTBMA and SMOTBMA), RIP, NRTS, SNRTS, COND, SCOND, and NSRU. (See Appendix B for explanation of terms.)

- LRU spares costs are developed from the LRU production costs quoted for the lot closest to the anticipated spares delivery. Delivery had to be estimated because the spares documentation is a deferred item for this proposal. Earliest delivery is estimated to be 12 to 15 months after provisioning, which in turn is estimated to be convenient to the government because it occurs some six months after the provisioning conference. The provisioning conference is estimated at 18 months after receipt of order (ARO) at the earliest. With an

anticipated start date of October 1988, delivery would occur from October through December 1991, which aligns with CLIN 0027's delivery schedule. Therefore, the de-escalated unit costs plus profit for the LRUs quoted under Pre-operational Spare (CLIN 0027) are used as cost inputs to equation C1.

- SRU spares costs are developed from the same LRU lot buy. Costs are obtained from the LRU cost breakdown for CLIN 0027 pricing.
- TWT spares costs inputs are calculated on the basis that it is a contractor repairable subassembly. The manufacturer has provided the following estimate of repairability and cost based on this experience.
  - Eighty percent of the returns require minor repairs equal to 15 percent acquisition cost.
  - Fifteen percent of the ret ırns require major repairs equal to 50 percent acquisition costs.
  - Five percent of the returns are beyond repair equal to 100 percent acquisition cost.

On that basis, traveling wave tube (TWT) repair is charged to material cost for off-equipment maintenance, since the repair will be accomplished by the manufacturer. Five percent of this repair consists of replacement of the TWT, since scrapping will be at the manufacturer's option. The replacement of TWTs also will not incur additional government spares. The following inputs were used for TWT modeling:

Acquisition Cost from CLIN 0027 breakdown:

SNRTS: set at 1

SCOND: set at 0

SDMC: set at 0.25

SDRCT: set at 2.25 (Contractor repair cycle time per AFLC model instruction)

SDMC: calculated as a mean repair cost from:

SDMC = 80% x 15% (Acq Cost) + 15% x 50% (Acq Cost)

= 5% x 100% (Acq Cost) = 0.25% Acquisition Cost

4. On-Equipment Maintenance Costs

These costs are calculated by equation C2 of the LCC model from the maintenance rate and the organizational-level repair time. The maintenance rate is calculated from the

predicted failure rate derated by the specified factor of 3 to 1. The failure rates for the LRUs and SRUs are developed from detailed circuit and component analyses, using the methodology of Section 2.0 of MIL-HDBK-217B. Operational versus rated stresses are developed from circuit analyses from which the failure rates are calculated. Estimated piece part ambient temperatures are used for the analyses. Temperatures are derived from a thermal analysis based on aircraft uninhabited environment except for the control indicator. The predictions reflect the production equipment configuration and the components. The detailed failure rates and predicted MTBFs are contained in the technical volume, with output data from the predictions contained in the appendix to the technical volume.

The maintenance times are developed from a detailed analyses using the techniques of Method IIB of MIL-HDBK-472 to calculate mean time to repair (MTTR). The MTTR takes into account the operation of the BIT and the time required to exercise BIT to fault isolate between antennas, the transmission lines, and the transmitter under some of the less dominant failure modes. False removals resulting from 2 percent BIT ambiguity are accounted for in the MTTR by adding the time to fault isolate, remove, replace, and check out the wrong LRU to the time to do the same for the properly isolated LRU. The degree of false removals and its affect on MTTR is calculated from a detailed BIT versus failure mode analysis. Its affect is negligible due to the extremely low probability of occurrence and its residing in ambiguities between readily accessible processor and transmitter LRUs in the fuselage.

The time to replace lamps in the control indicator is not included as an input because the LCC programming does not calculate higher level LRU repair if any portion of an LRU is repaired in place. Therefore, RIP must be 0. The effect of this is negligible, since the failure rate of the lamps is extremely low.

5. Off-Equipment Maintenance Cost

These costs are calculated by equation C3 of the logistics support cost (LSC) model from the maintenance rate, the LRU and SRU repair times, and cost of repair material. The maintenance rates and repair times are developed from reliability and maintainability discussed in the previous paragraph. The MTTRs reflect use of the planned support equipment because the maintainability analyses calculated fault isolation time from the intermediate-level draft diagnostics, which are structured around the AN/ALQ-XXX test set capabilities.

Repair material consists primarily of replacement piece parts and government furnished inputs for consumables. The cost of the average piece part for each SRU is calculated from the cost and failure rate of each component in an SRU as obtained from the bill of materials and reliability stress analyses. The failure-rate-weighted average piece part cost divided by the SRU cost provides the percent piece part cost. Since this is a relative number, the same SRU cost as developed for the spares costs is used.

The TWT is modeled as contractor repairable. Its repair labor is, therefore, translated to repair material cost, since no Air Force labor will be used for its repair.

6. Cost of Inventory Entry and Supply Management

These costs, which are limited to base supply and management by the LCC model, are calculated by equation C4 from the quantity of new and already stocked repairable assemblies, consumables, and LRUs. These quantities are obtained from the drawings and non-standard parts determination by the reliability parts group. All parts, including piece parts contained on SRUs, are classified in this manner for use in trade-offs in the course of development.

Contractor inputs to equation C4 are PA, PP, and SP.

7. Cost of Support Equipment for the AN/ALQ-XXX

The commonality of LRUs and SRUs between the various applications of the AN/ALQ-XXX permit the same support equipment to be used for all versions. The existing automatic test set is not used in the basic modeling because there is no mention of its application or cost in the RFP. In the basic model, two intermediate-level test sets per base, and one depot-level test set are input to equation C5, as required.

The support equipment costs for the support complex are provided under CLINs 0002, 0007, 0021 and 0024. These costs include the cost of the common equipment contained in the intermediate- and depot-level test sets and are the sum of the quoted CLINs 0002, 0007, 0021, and 0024 de-escalated to FY 1982 dollars. A potential for savings exists in the form of handling fee, administrative costs, and profit, if the government is to furnish and install the common commercial equipment.

8. Cost of Personnel Training for the AN/ALQ-XXX

The cost of training is usually not required to be bid during a development phase proposal; therefore, an estimate is made of the training time and training equipment. This is based on the recommendation contained in the Training Planning Information Documents, data item AOOJ, prepared for the proposal of this program. The course outlined in this document addressed operation and maintenance at the intermediate-level (LRU repair), based on experience. Also considered was the equipment's ease of maintenance and the proposed, thorough step-by-step diagnostic (logic tree) troubleshooting procedures. From these considerations, a two-day classroom/hands-on maintenance course for each LRU was considered more than adequate.

Depot-level training for SRU repair was not considered, since the circuits used in the AN/ALQ-XXX are relatively classic, and the students should be familiar with the basics of the circuits. The SRUs are all constructed for ease of maintenance for intermediate-level skills, and are all similar to each other. Therefore, it is estimated that an average of one-half day per SRU would be ample training time.

The training equipment is considered to consist of one system in the form of one bench mock-up, CLIN 0002 plus 0007AD, and one set of intermediate- and depot-level test equipment. Since the AN/ALQ-XXX test set, CLIN 0007AC, contains the intermediate-level test set, which is independently operable, the depot test set was considered adequate with the addition of one mobile bench CLIN 0007AB. Because two depot test sets are contained in CLIN 0007AC and only one is needed at the depot, due to a calculated average loading of 67 percent for the test set exhibiting the heaviest usage when all AN/ALQ-XXX configurations are serviced by the same intermediate level, the second one is assumed to be scheduled for training. Similarly, one mobile bench under the extra quantities in CLIN 0007 is assumed for training. Training costs are computed by equation C6 with the following contractor inputs: TCB, TCD, TE, N, QPA, SQPA, MOTBMA, RIP, TRS, SRTS, NRTS, SNRTS, IMH, RMH, BMH, SBMH, DMH, SDMH. To avoid double charging for support equipment TE was set to zero.

9. Cost of Management and Technical Data

The cost of management and maintenance data (technical orders) is calculated with Equation C7. The difference in cost between data item AOOL and the documentation cost in Equation C7 is added to the support costs as part of CLIN 005. As required, the

remaining costs for program management and engineering data contained in CLINs 0005, 0006, 0011, and 0012 are obtained from the proposal. They include profit and are de-escalated based on their delivery schedule. Page counts for the input to Equation C7 are obtained from the page count contained in the proposal for data item AOOL.

The contractor inputs to Equation C7 are H, JJ, QPA, SQPA, MOTBMA, SMOTBMA, and RIP.

10. Cost of Installation and Checkout and Integrated Test Operations

As required, these costs are the de-escalated costs for CLINs 0009, 0028, and 0029, including profit.

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